Economics and Biomass Utilization

Design and Objectives of FTM–West Model

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***Abstract**—The FTM–West ("fuel treatment market" model for U.S. West) is a dynamic partial market equilibrium model of regional softwood timber and wood product markets, designed to project future market impacts of expanded fuel treatment programs that remove trees to reduce fire hazard on forestlands in the U.S. West. The model solves sequentially the annual equilibria in wood markets from 1997 to 2004 and projects annual equilibria from 2005 to 2020 using detailed assumptions about future thinning programs and market trends. FTM–West was designed specifically to account for economic complexities that stem from unconventional size distributions of trees and logs removed in thinning operations (compared with conventional timber supply in the West). Tree size directly influences market value and harvest cost per unit volume of wood; log size influences product yield, production capacity, and processing costs at sawmills and plywood mills. FTM–West provides a tool to evaluate future market scenarios for large-scale fuel treatment programs with various thinning regimes that may have varying costs and yield wood with divergent size class distributions. The model provides a capability to analyze and project how much harvestable wood the markets can absorb from thinning programs over time and the regional timber price and timber harvest impacts of expanded thinning under various assumptions about fuel treatment program subsidy or administrative costs, variations in thinning regime, or alternative projections of future product demands across the spectrum of products ranging from wood fuel to lumber, plywood, and wood fiber products.*

Introduction

Decades of fire suppression, reduced timber harvests on public lands since the 1980s, and a build-up of standing timber inventories in fire-prone forested regions of the western United States have created conditions susceptible to catastrophic wildfires. Expanded programs of systematic stand density reduction through mechanical thinning on public lands may reduce fuel build-up. Timber market consequences of such programs depend on the scale of program and the type of treatment regime. This paper describes the design and objectives of an economic model that can project timber market impacts of expanded fuel treatment programs in the U.S. West.

The "fuel treatment market" model for the U.S. West (FTM–West) employs the Price Endogenous Linear Programming System (PELPS). PELPS is a general economic modeling system developed originally at the University of Wisconsin (Gilless and Buongiorno 1985, Calmels and others 1990, Zhang and others 1993) and more recently modified for applications at the Forest Products Laboratory (Lebow and others 2003). PELPS-based models employ the technique of spatial equilibrium modeling (Samuelson 1952), with periodic (for example, annual) market equilibrium solutions obtained by economic optimization. Solutions are derived by maximization of consumer and producer surplus, subject to temporal production capacity

In: Andrews, Patricia L.; Butler, Bret W., comps. 2006. Fuels Management—How to Measure Success: Conference Proceedings. 2006 28-30 March; Portland, OR. Proceedings RMRS-P-41. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

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constraints, transportation and production costs, and price-responsive raw material supply curves and product demand curves, all of which can be programmed realistically to shift over time and respond to endogenous shifts in market conditions. FTM–West employs the FPL version of PELPS (called FPL–PELPS), Lebow and others (2003) and earlier PELPS publications provide further mathematical details about the modeling system. PELPS has been used fairly widely for partial market equilibrium models of timber and forest products for many years (for example, Buongiorno and others 2003, Zhang and others 1996, ITTO 1993).

Structure of FTM–West

Forest sector market models commonly include structural features of wood product markets, such as a regional market structure with regional product demand curves, regional timber supply curves, interregional transportation costs, and regional production capacities and manufacturing costs. Those general structural features were included also in FTM–West. In addition, FTM–West was designed with other features to account for economic complexities that can arise with utilization of wood from fuel treatment programs, which may have a more divergent distribution of volume by tree size class than does conventional timber supply (for example, wood from fuel treatments may have a larger fraction of volume in smaller trees than conventional timber supply).

General Design Features

Among general design features, FTM–West included demands for more than a dozen forest product commodities encompassing the full spectrum of forest products produced from softwood timber in the U.S. West, three product demand regions, eight production or supply regions, and estimated wood supplies from conventional timber supply sources and from future fuel treatment programs (assumed to be primarily softwoods). Table 1 summarizes the regional and commodity structure of the model.

The model included demand only for forest products produced from softwood timber in the U.S. West, a partial representation of total U.S. and global demands for forest products. Fairly simple demand curves were specified in the model based on an assumption that demands for all products are inelastic (price elasticity of demand ranged from –0.3 to –0.8 among the various products). Aggregate demand quantities for each product were equated to product output data for the U.S. West in the base year (1997) and proportioned to each of the three product demand regions using estimates of regional shipments

Table 1—Regional and commodity structure of FTM–West model.

Supply/production regions	Demand regions	Demand commodities
Coast PNW (OR, WA)	U.S. West	Softwood lumber & boards
Eastern Washington	U.S. East	Softwood plywood
Eastern Oregon	Export market	Poles & posts
California		Paper (five grades)
Idaho	*Supply commodities*	Paperboard (three grades)
Montana	"Pines"	Market pulp
Wyoming–South Dakota	"Non-Pines"	Hardboard
Four-Corners (UT, CO, AZ, NM)	(trees, logs, chips)	Fuelwood

from the West. Product output was based on data published by industry associations, such as WWPA (various years) for lumber, AF&PA (2005) for pulp and paper, and APA–The Engineered Wood Association (various years) for plywood. FTM–West was designed to derive annual market equilibria sequentially over a 24-year period, 1997 to 2020, which permitted testing and calibration of model solutions against overlapping historical data (to 2004). Demand curves were shifted each year based on historical shifts in production in the U.S. West (1997 to 2004), and the model was programmed with a set of assumed future growth rates in regional demand (2005 to 2020) for each forest product commodity. Demand growth rate assumptions matched recent Forest Service Resources Planning Act (RPA) Assessment projections (2005 draft RPA timber assessment report).

Similarly, simple supply curves were used to model conventional softwood timber supply in each of the eight supply regions, while exogenous estimates of wood supply from treatment programs (upper bounds on harvest quantity and harvest costs) were introduced as policy or program variables. Estimates of wood supply from fuel treatment programs were obtained from the Fuel Treatment Evaluator, FTE v. 3.0 (Skog and others 2005). Most conventional timber supply in the U.S. West is currently obtained from timber harvest on state and private forestlands, subjected mainly to even-aged timber management. Thus, inelastic supply curves were used for conventional timber supply (with an assumed price elasticity of 0.7). Conventional timber supply curves were programmed to shift over time in direct proportion (1:1 ratio) to net growth in softwood timber inventory volumes on state and private timberland within each supply region. Annual net growth in state and private timber inventories are computed in the model by deducting from standing timber inventories the harvest volumes from the preceding year and adding timber volume growth based on recent growth rates in each region (Smith and others 2004). Thus, FTM–West incorporated techniques similar to those used in the Forest Service RPA Assessment to model conventional timber supply (that is, inelastic supply curves shifted over time in proportion to projected net growth in timber inventories).

In addition to supply and demand curves, FTM–West incorporated estimates of manufacturing capacities for the various products in each of eight production regions, manufacturing cost data, and transportation cost data (for wood raw material and product shipments). A feature of PELPS is that production capacities shift over time in response to projected market conditions, and in FTM–West we used a representation of Tobin's *q* model to project regional capacity change as a function of the ratio of shadow price (or value) of production capacity to cost of new capacity (Lebow and others 2003).

Structural Complexities in Wood Utilization

Beyond general elements of model structure, FTM–West incorporated some unique features to account for economic complexities that were known to be associated with utilization of wood from fuel treatments. Specifically, it was known that the size-class distribution of wood harvest (the distribution of wood volumes by tree diameter class) may be significantly different for wood removed in fuel treatments than for conventional timber supply. Also, it is fairly well known that timber market value and harvest costs per unit volume are highly dependent on tree size class or diameter, whereas mill production capacity, processing costs, and product yields also vary with log diameter, particularly at lumber mills and plywood mills.

Divergent Sizes of Trees and Logs—In recognition of divergent size classes of trees harvested, both the conventional timber harvest and the exogenously specified wood harvest from fuel treatments were modeled in FTM–West by 2-inch (5-cm) diameter classes, ranging from trees <5 inches d.b.h (diameter at breast height) to trees >15 inches d.b.h. Thus, all wood supply is disaggregated into seven tree size classes, each of which can assume a unique market value in the FTM–West model. Furthermore, each tree size class yields different proportions of logs (by 2-inch log size class) along with variable quantities of wood chip raw materials. Estimates of actual log and chip volume yields were derived for each tree size class and for each of the eight supply regions based on recovery data from regional utilization studies conducted at the Forest Service Pacific Northwest (PNW) Research Station (compiled from mill studies by Dennis Dykstra, PNW Station).

Figure 1 illustrates divergent distributions of harvest volume by tree size class as estimated for conventional timber harvest in the U.S. West (in 1997) and for two fuel treatment thinning program regimes (derived from the FTE program; Skog and others 2005). Both the even-aged TFB (thin-from-below) treatment regime and the uneven-aged SDI (stand density index) treatment regime yielded proportionately more volume in smaller trees (size classes less than 9 inches d.b.h.) than did conventional timber harvest, but the SDI treatment also yielded more volume in larger trees (>15 inches d.b.h.).

Figure 2 illustrates the West-wide average log and chip recovery potential from each tree size class (averages for all eight regions in FTM–West). In general, smaller trees can yield only small logs and a high proportion of volume in wood chips, whereas bigger trees can yield more volume in larger logs (which have generally higher value) and a smaller proportion of volume as chips.

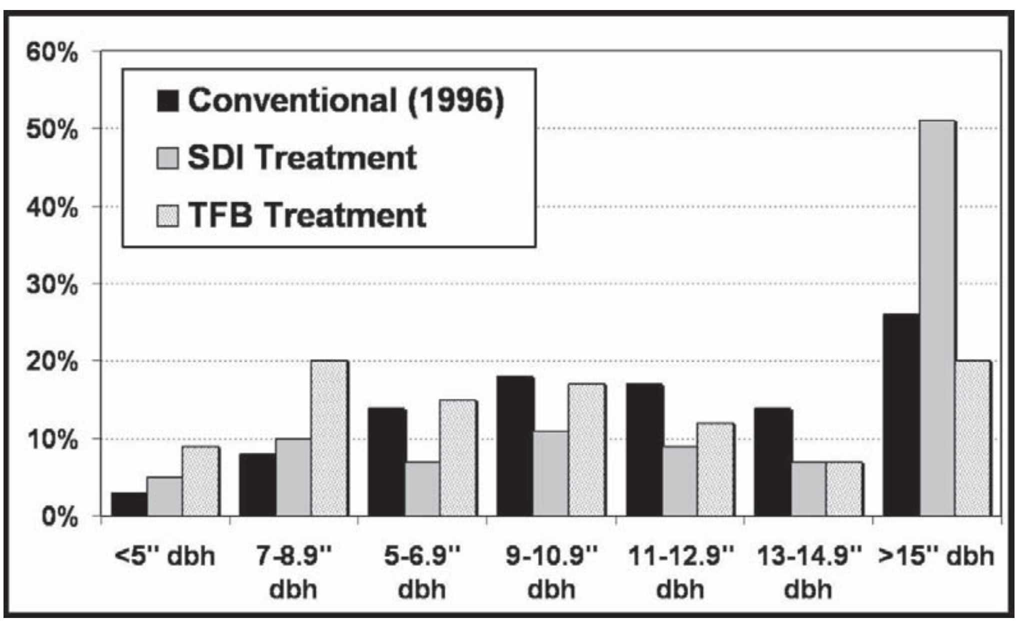

Figure 1—Estimated volume distributions by tree size class for conventional timber harvest and for wood from fuel treatment regimes on federal lands in U.S. West.

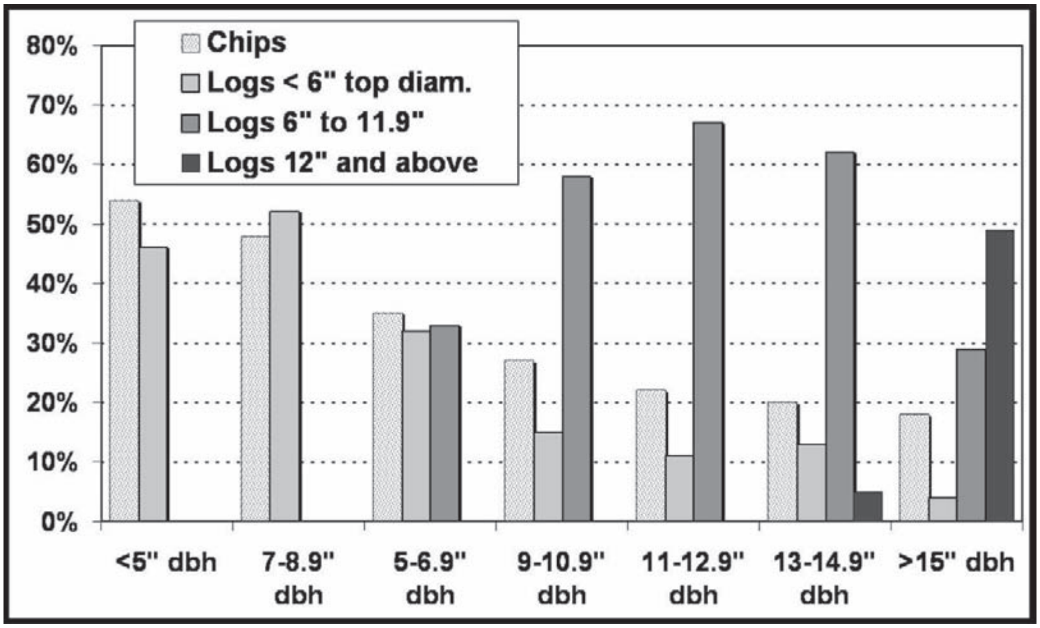

Figure 2—West-wide average log and chip recovery potential (percentages of cubic wood volume recoverable as chips and logs of various sizes) for different tree diameter classes.

Variable Stumpage Values and Variable Harvesting Costs—Harvesting costs per unit of wood volume vary with tree size class due to efficiencies gained in harvesting larger trees with more wood volume per tree or per log harvested. Thus, in addition to modeling wood supply in FTM–West by size class of trees and logs, we used harvest cost models to estimate harvesting costs for each tree size class. Harvesting costs for wood removed in fuel treatments were estimated by the FTE program (Skog and others 2005) using the calculation routine from *My Fuel Treatment Planner* (Biesecker and Fight 2005). Timber harvesting costs for conventional timber supply were estimated by tree diameter class using a conventional timber harvest cost model by Keegan and others (2002).

For the simulated fuel treatment programs, we adopted a policy assumption that fuel treatment managers on federal lands would require removal of all tree size classes marked for thinning, based on an assumption that fuel treatment policies would not allow "high-grading" or just the removal of bigger and more valuable trees. Under that policy assumption, the harvesting and transportation costs applied to all wood from fuel treatments are the volume-weighted average costs across all tree size classes. Note that average costs for fuel treatments (across all size classes) were estimated to be higher than conventional timber harvesting and transport costs in the West.

Figure 3 shows our West-wide averages of wood harvesting costs, wood transport costs to mill, and stumpage costs in dollars per thousand cubic feet (MCF) as assumed or as estimated in the FTM–West model. Costs for conventional timber supply are differentiated by tree diameter class, with notably higher estimated stumpage values for larger trees (2005 equilibrium values).

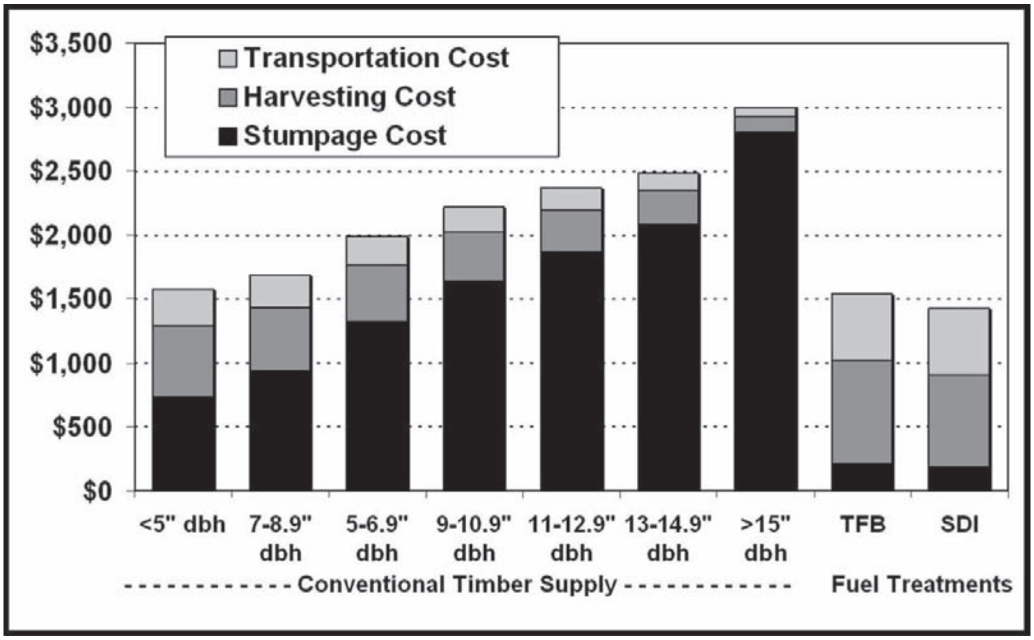

Figure 3—West-wide averages of 2005 delivered wood costs ($/thousand cubic feet) by tree diameter class for conventional timber harvest and wood from fuel treatments, including stumpage cost (2005 equilibrium values computed by FTM–West), harvesting cost, and transportation cost.

In our fuel treatment program scenarios we assumed a hypothetical harvest fee (equivalent to stumpage fee) of $500 per acre, representing a nominal fee for administrative costs. That fee translates to $214/MCF harvested for the TFB thinning program and $188/MCF for the SDI program.

As illustrated in figure 3, the assumed harvest fees (stumpage costs) for the hypothetical fuel treatment programs are considerably lower than the estimated stumpage market values for conventional timber supply in the region, but the estimated harvest and transportation costs for the fuel treatments are considerably higher than those for the conventional timber supply. In essence, we assumed that the hypothetical fuel treatment programs would offer wood to the market at low stumpage fees that would compensate somewhat for the higher harvest and transport costs of fuel treatments. This is purely a hypothetical assumption, and future fuel treatment programs might potentially charge higher or lower fees. Note also that harvest and transportation costs shown here are averages that include costs for both logs and chips delivered to mills.

Variable Product Yields and Variable Sawmilling Capacity—Sawmill capacities are generally constrained by primary saw rigs that break down logs at the front end of sawmills. Primary breakdown saws (or “head rigs”) are typically designed to process logs within certain size ranges, some designed to process small logs and some designed to process large logs. Small log mills run logs end-to-end at fairly constant speed, and within a feasible range of equipment design, a larger log yields more product because each cut generates more volume (Fight 2002). In contrast, large log mills may not process logs in one pass but may require multiple passes before logs are sufficiently broken down to permit further processing, which results in unproductive dead time between passes. Furthermore, the larger cross-sectional areas of cuts usually require a slower feed rate with large logs. Thus, effective lineal throughput of logs at large log mills is less than that of small log mills, but the greater volume of wood in each lineal foot more than compensates for the slower feed rate.

In general, sawmill output capacity is determined by (1) the lineal feet of logs that the sawmill is capable of processing in a given amount of time (throughput), (2) the volume of wood contained in each lineal foot of log throughput, and (3) the lumber recovery factor (LRF), which measures yield of lumber in board feet from each cubic foot of log throughput. However, parameters (2) and (3) are strongly influenced by log diameter, and thus lumber output capacity of sawmills varies with the size of log inputs. Product recovery per cubic foot of log input for both lumber and plywood generally increases with log size. Figure 4 is a plot of estimated lumber recovery (in board feet) and plywood recovery (in square feet) per cubic foot of log input by log diameter as estimated for the FTM–West model (Williston 1981).

Sawmill industry mill capacities are conventionally reported in board feet of lumber output rather than lineal feet of log throughput (for example, see Spelter and Alderman 2005). To estimate equivalent sawmill capacities in lineal feet of log throughput, we started by obtaining wood consumption data by log size, available for the states of Washington (Larsen and Aust 2000) and Oregon (Ward and others 2000). In each state the volumes of logs processed by sawmills, expressed in board feet, were provided for four log size classes, as shown for the state of Washington in table 2, row 1.

We then estimated a corresponding distribution of tree harvest volume by tree diameter class (d.b.h.) that would produce a mix of logs (table 2, row 2) exactly matching the actual survey data on log size distribution (table 2, row 1). To do this, we started with data on log recovery volumes from

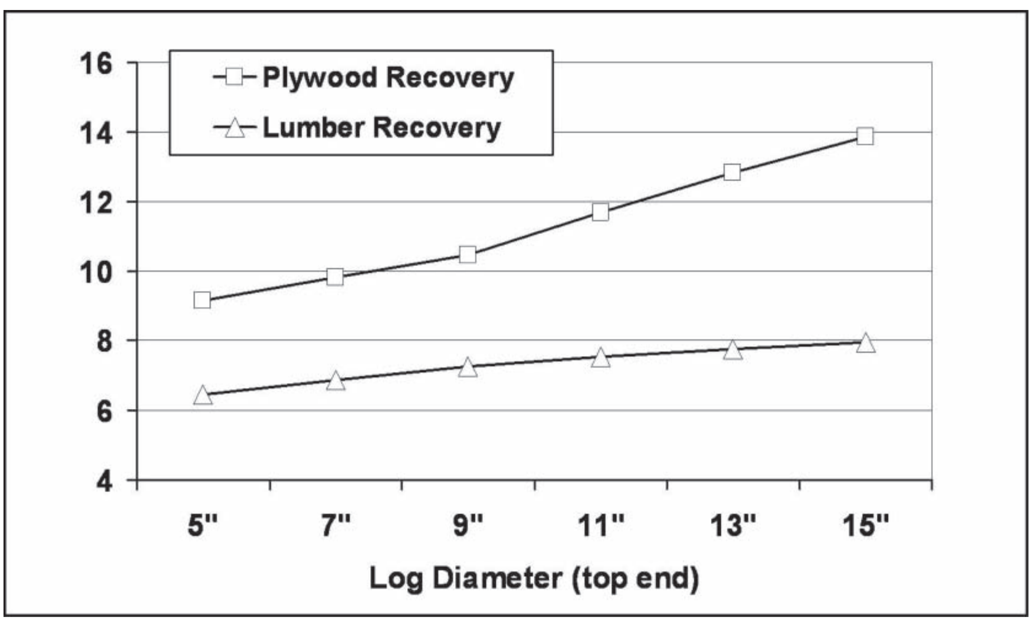

Figure 4—Estimated lumber recovery (board feet) and plywood recovery (square feet) per cubic foot of wood input by log diameter.

Table 2—Log volumes in coastal Washington.

Log diameter class (top end diameter) (inches)	<5	5–10	11–20	21+	Totals
Log volumes (log scale), actual survey data (million board feet)	124.4	908.8	812.0	137.4	1982.7
Log volumes derived from assumed tree harvest (million board feet)	124.5	908.8	812.0	137.4	1982.7
Derived lineal feet of logs (millions)	170.2	541.1	127.2	6.1	844.6
Average cubic feet per lineal foot	0.164	0.457	1.345	3.447	0.553
Derived cubic feet of logs (millions)	27.9	247.4	171.0	21.2	467.4
Average board feet (log scale) per cubic foot	4.46	3.67	4.75	6.49	

field studies conducted over the years at the Pacific Northwest Research Station, as compiled and analyzed by Dennis Dykstra. By an iterative process, we varied the numbers of trees within each tree diameter class until the derived log volumes matched the survey data (table 2, row 2). Then, multiplying numbers of trees by lineal feet of logs from each tree gave derived estimates of lineal log throughput consistent with reported log volumes (table 2, row 3). Regional industry throughput capacity in lineal feet was derived by dividing the estimated lineal throughput by the observed regional capacity utilization ratio (derived from WWPA lumber output data and capacity data from Spelter and Alderman 2005) Thus, we obtained estimates of lineal log throughput capacities at sawmills in western states and FTM–West regions that were equivalent to lumber output capacity in those states and regions. Similarly, multiplying the number of logs by the cubic volume of each log produces estimates of the equivalent cubic foot volumes of mill throughput (table 2, row 5).

To model sawmill capacity in relation to log size, we had to estimate the relationship between lumber output and log size for a given regional log throughput capacity. In other words, we assumed that sawmill capacity is constrained primarily by the lineal log throughput capacity of mill head rigs, but variation in log size can result in marginal shifts in lumber output capacity. Again, for each log size, two variables connect log throughput to equivalent board feet of lumber output: cubic volume of wood in an average lineal foot of log throughput (what we term the V factor) and lumber recovery factor (LRF), the board feet of lumber yielded by a cubic foot of log throughput. Given industry throughput capacity in lineal feet, along with the V and LRF factors, the theoretical board foot capacity for each log size class can be determined. However, portraying lineal throughput capacity as invariant with respect to log size is unrealistic. As logs get bigger, at some point the log breakdown requires multiple passes through the head saw and/or feed speeds must be decreased (Williston 1976). Because we do not have mill capacities by feed speed limits, we approximated this aspect of sawmilling by introducing an arbitrary log speed adjustment factor, effectively speeding processing up for smaller logs and slowing it down for larger logs. This adjustment resulted in a realistic representation of how sawmill throughput would respond to changing log diameters and produced throughput capacities from which board foot capacities were derived by multiplying by the V and LRF factors, as shown in table 3.

Table 3—Board foot lumber output capacity as a function of log size for given log throughput capacity (lineal feet of log throughput).

Log size class (inches)	Capacity (lin. ft)	Adjustment for log speed (%)	Adj. cap. (lin. ft)	V	LRF	Capacity (board ft)
<4	844.6	73	1,461	0.15	6.33	1,387
4–5.9	844.6	52	1,284	0.27	6.44	2,233
6–7.9	844.6	24	1,047	0.51	6.87	3,668
8–9.9	844.6	7	904	0.65	7.25	4,260
10–11.9	844.6	–6	794	0.91	7.54	5,448
12–13.9	844.6	–15	718	1.30	7.77	7,252
>14	844.6	–32	574	2.52	8.20	11,861

It is self-evident that the V factor (cubic volume per lineal foot of log throughput) increases with log size because the wood volume in a lineal foot increases by the diameter of the log squared. The LRF also increases because the share of edgings and slabs becomes a smaller fraction of total volume as logs increase in size (fig. 1).

Variable Manufacturing Costs—In a similar vein, the V and LRF factors affect non-wood manufacturing costs. A mill's labor costs and capital costs, for example, are invariant with respect to the size of a log that is momentarily being processed, and thus they are marginally fixed costs relative to log throughput but variable with respect to product output. Varying log size marginally affects lumber output, and thus fixed costs will be written off against varying volumes of product output. Thus, manufacturing costs per board foot of lumber output vary in FTM–West by log diameter class.

To estimate how manufacturing costs vary with log size class we first developed estimates for each region of average industry non-wood costs (labor, energy, materials, supplies, overhead, and depreciation) per unit of mill output. Multiplying the unit cost estimates by the base year output gave the total dollar value of non-wood manufacturing costs for each region. Given estimated relationships between output capacity and log size, as derived above for each region, we calculated the theoretical manufacturing costs for each log size at a constant log throughput volume as our first approximation of unit costs by log size, which exhibit a pronounced inverse relationship to log diameter (as shown by the "constant throughput" relationship in figure 2). However, again, it would be unrealistic to assume that lineal log throughput speed could remain constant with varying log diameter, so we applied again the log speed adjustment (table 2) to reflect accelerated throughput with smaller logs and slower throughput with larger logs. The result is the relationship shown as the "variable throughput" cost curve in figure 5, which we used to model lumber manufacturing costs by log diameter in FTM–West. Despite the log speed adjustment, there is a big cost difference between processing small logs and large logs.

Plywood manufacturing capacity, manufacturing costs, and product recovery are modeled in an identical manner, using the same V factors and replacing LRF by the plywood recovery factor, whose behavior is identical to the LRF for the same basic reasons (fig. 4).

Finally, as noted previously, regional production capacities in the FTM–West model will shift over the projection period from 2005 to 2020 in response to

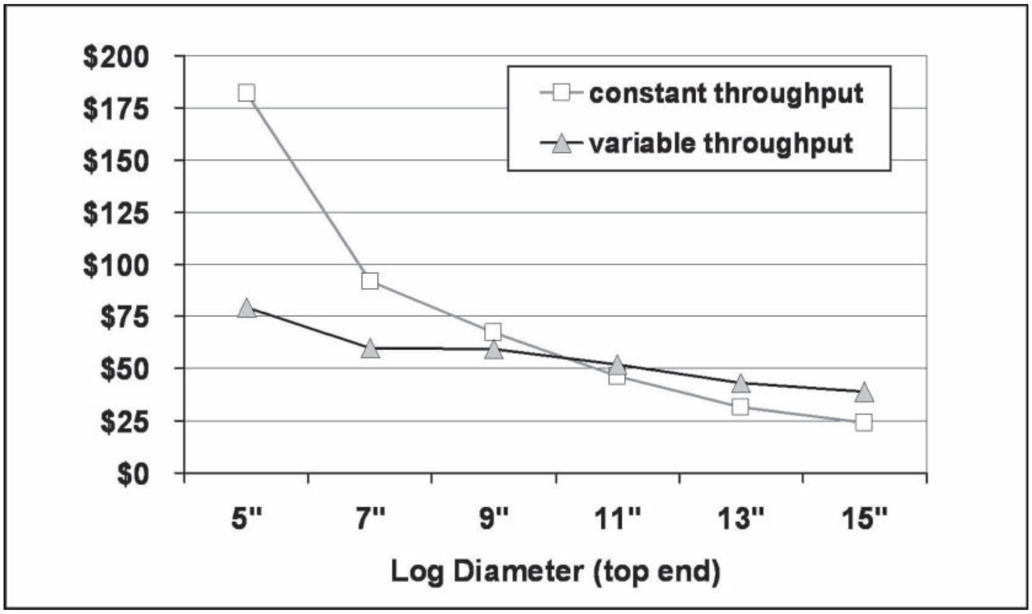

Figure 5—Non-wood lumber manufacturing costs ($/thousand board feet) with constant log throughput and variable-speed log throughput assumptions.

projected economic profitability of investments (Tobin's *q* ratio), simulating long-run capital investment responses to economic opportunities. In scenarios that introduce increased supply of wood from fuel treatment programs, we found that the model responds with capacity expansion, increased regional wood harvest, and displacement of conventional timber harvest by wood from fuel treatments. However, treatment regimes that introduce marginally higher proportions of small-diameter wood than conventional timber harvest will also marginally offset regional production capacities, reduce average product recovery, and increase manufacturing costs for lumber and plywood. Those impacts affect the producer surplus and consumer surplus consequences of fuel treatment programs. Net market welfare impacts of alternative treatment regimes are described in a companion paper in these proceedings (Kramp and Ince 2006).

Summary

The development of FTM–West provided a tool to evaluate future market scenarios for large-scale fuel treatment programs with various thinning regimes that may have varying costs and may yield wood with divergent size class distributions. It also provided a capability to analyze and project how much harvestable wood the markets can absorb from thinning programs over time and the regional timber price and timber harvest impacts of expanded thinning under various assumptions about fuel treatment program subsidy or administrative costs, variations in thinning regime, or alternative projections of future product demands across the spectrum of products ranging from wood fuel to lumber, plywood, and wood fiber products.

Acknowledgments

This study was funded in part by the Joint Fire Science Program (JFSP), a partnership of six federal agencies: USDA Forest Service, Bureau of Indian Affairs, Bureau of Land Management, National Park Service, U.S. Fish and Wildlife Service, and U.S. Geological Survey. Additional in-kind contributions were provided by researchers at the USDA Forest Service Forest Products Laboratory (FPL) and Pacific Northwest Research Station (PNW). Andi Kramp of FPL helped enter data input for the FTM–West market model and assisted in running the model and interpreting model results. Ken Skog of FPL assisted in developing treatment program scenarios for FTM–West using the Fuel Treatment Evaluator (FTE, version 3.0). Dennis Dykstra of PNW provided estimates of log and chip volume yields for each tree size class in each of the eight supply regions of FTM–West, based on data from regional wood utilization studies. The study was part of a larger JFSP-funded project, identified as JFSP project 01-1-2-09, "A national study of the economic impacts of biomass removals to mitigate wildfire damages on federal, state, and private lands," coordinated by Jeffrey Prestemon and Karen Lee Abt of Forest Service Southern Research Station (SRS). The authors sincerely appreciate the consultation provided by the project coordinators, as well as consultation on the PELPS modeling system from Patti Lebow of FPL, additional data input from Matt Alderman of FPL, and consultation or input from other members of the JFSP project, including Roger Fight and Jamie Barbour of the PNW and Bob Rummer and Robert Huggett, Jr., of SRS.

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FTM-West Model Results for Selected Fuel Treatment Scenarios

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***Abstract**—This paper evaluated potential forest product market impacts in the U.S. West of increases in the supply of wood from thinnings to reduce fire hazard. Evaluations are done using the Fuel Treatment Market–West model for a set of hypothetical fuel treatment scenarios, which include stand-density-index (SDI) and thin-from-below (TFB) treatment regimes at alternative levels of harvest administrative fees or subsidies. Results show that even with industry bearing the assumed administrative costs of thinning programs, substantial volumes of wood could be thinned, but more so in coastal regions than inland regions of the West. Also, replacing administrative fee assumptions with hypothetical removal subsidies increases the proportion of harvestable wood removed; a sensitivity observed primarily in the inland regions. Results show also that wood removals from fuel treatment programs could displace a large fraction of timber supply from conventional sources, reducing regional timber harvest and timber revenues that would otherwise be projected to increase for state and private timberland managers in the West. The SDI thinning regime can result in potential gains in forest product consumer surplus that more than offset losses in timber producer surplus, resulting in positive net market welfare, while the TFB regime can produce the opposite result (negative net market welfare).*

Introduction

The Fuel Treatment Market (FTM) model for the U.S. West, or FTM–West, is a dynamic partial equilibrium model of the markets for softwood timber and forest products produced in the western United States. The model projects the market for wood from fuel thinning treatments along with the market for timber from conventional sources in order to project the market impacts of fuel treatments (Ince and Spelter, this proceedings; Ince and others 2005). At the present time, only a small fraction of the fuel treatment acreage on federal lands in the U.S. West involves wood harvest (over 90% of the fuel treatment acreage involves prescribed burning or mechanical treatment without wood byproduct removal). This paper illustrates projected market impacts of hypothetical expanded fuel treatment programs involving thinning and wood removal on federal lands in the West.

Different scenarios can be run in the FTM-Westmodel with different hypothetical forest treatment programs or with no treatment program at all. The two hypothetical thinning regimes analyzed in this study were created using the Fuel Treatment Evaluator (FTE 3.0) model (Skog and others 2006) and the areas considered for treatment were NFS and other federal land (BLM, BIA, etc.). The thinning regimes were developed by a team of researchers whose objective was to identify places where the use of woody biomass from

In: Andrews, Patricia L.; Butler, Bret W., comps. 2006. Fuels Management—How to Measure Success: Conference Proceedings. 2006 28-30 March; Portland, OR. Proceedings RMRS-P-41. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

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thinning can best help pay for hazardous fuel reduction treatments. The effort identified USDA Forest Service Forest Inventory and Analysis (FIA) plots on timberland in 12 western states—127 million acres—that passed screens excluding high severity fire regime forest types (where crown fires are normal), low fire hazard plots, plots in roadless areas, and plots in selected counties on Oregon and Washington where treatments would be done primarily for purposes other than fire hazard reduction. Twenty four million acres were identified as eligible for treatment, of which 14 million acres are on federal land. Eligible acres received simulated treatment by one of two silviculture treatment regimes to meet certain fire hazard reduction targets if the treatment would provide at least 300 ft^3/acre (~ 4 oven-dried tons/acre). The SDI treatment removed trees across all age classes to leave an uneven-aged stand. The TFB treatment removed trees beginning with the smallest to leave an uneven-aged stand. The paper by Skog and Barbour (this proceedings) explains the SDI treatment regime (a combination of treatments 2A and 4A) and the TFB treatment regime (a combination of treatments 3A and 4A).

Each regime was run with two different cost assumptions (making four total scenarios). In one scenario, administrative fees (stumpage fees) were levied on the wood available for treatment to pay for the estimated average cost per acre to the Forest Service to make the wood available ($500 per acre), whereas the other scenario eliminated the fee and instead offered a subsidy for the wood ($200 per MCF). The sensitivity of the volume of wood treated to the stumpage fee or subsidy was not intensely analyzed in this study, and therefore the cost assumptions are not assumed to maximize possible revenue to the Forest Service or the volume of wood treated under any constraints.

Scenario Inputs

Two different hypothetical forest treatment regimes were evaluated using the FTM-Westmodel, the inputs of which were obtained using the FTE model. In this paper they are referred to as SDI and TFB, respectively. The FTM-West required as input three different aspects of the scenarios: the volume distribution of available wood by d.b.h. class for each supply region (table 1), the volume of wood to be made available for treatment in each year for each supply region, and the weighted average cost of the wood from treatments, which includes harvest and transport costs and possibly an administrative cost or subsidy, also in each supply region. Most of the figures in this paper are aggregated for the whole U.S. West. As Skog and others (this proceedings) mention, the SDI scenarios consist of more (about twice as much) total wood

Table 1—Volume of wood by diameter at breast height class for two hypothetical thinning programs compared with 1997 estimates on conventionally harvested wood (Ward and others 2000; Larsen and others 2000). Rows might not add to 100% due to rounding.

	Wood by diameter at breast height class						
	<5	5 to 6.9	7 to 8.9	10 to 11.9	12 to 13.9	14 to 15.9	>15
	Inches						
TFB	9%	20%	15%	17%	12%	7%	20%
SDI	8%	10%	8%	10%	9%	6%	48%
Conventional (1997)	3%	8%	14%	18%	17%	14%	27%

and acres available than the TFB scenarios (figures 1 and 2). Also note that the FTE only gives the total amount of wood available for treatments in each region, so a logarithmic-growth function was used to smooth this amount over a 16-year period, 2005 to 2020. Each scenario was run once with an added $500 per acre administrative fee (equivalent to a stumpage fee) for wood available from forest treatments, which is estimated to cover the cost of making the wood available, and once with no fee and an unconstrained $200/MCF subsidy.

In all the effects discussed here (volume harvested, timber prices, producer and consumer surplus) except the change in net market welfare, the SDI scenarios had larger impacts compared with the TFB scenarios. Similarly, the scenarios where forest treatments were subsidized had larger effects when compared with the scenarios that required administrative fees.

Volume Harvested and Timber prices

In all four scenarios, more than half of the wood made available from forest treatments was utilized (table 2). Subsidizing the programs resulted in an additional 3.6 and 3 billion cubic feet representing 16% and 30% of the total FTE volume for the SDI and TFB programs, respectively. This additional wood treated was located exclusively in the interior region of the U.S. West because in every scenario 100% or nearly 100% of wood made available in the coastal region (Pacific Northwest and California coasts) was treated. For the

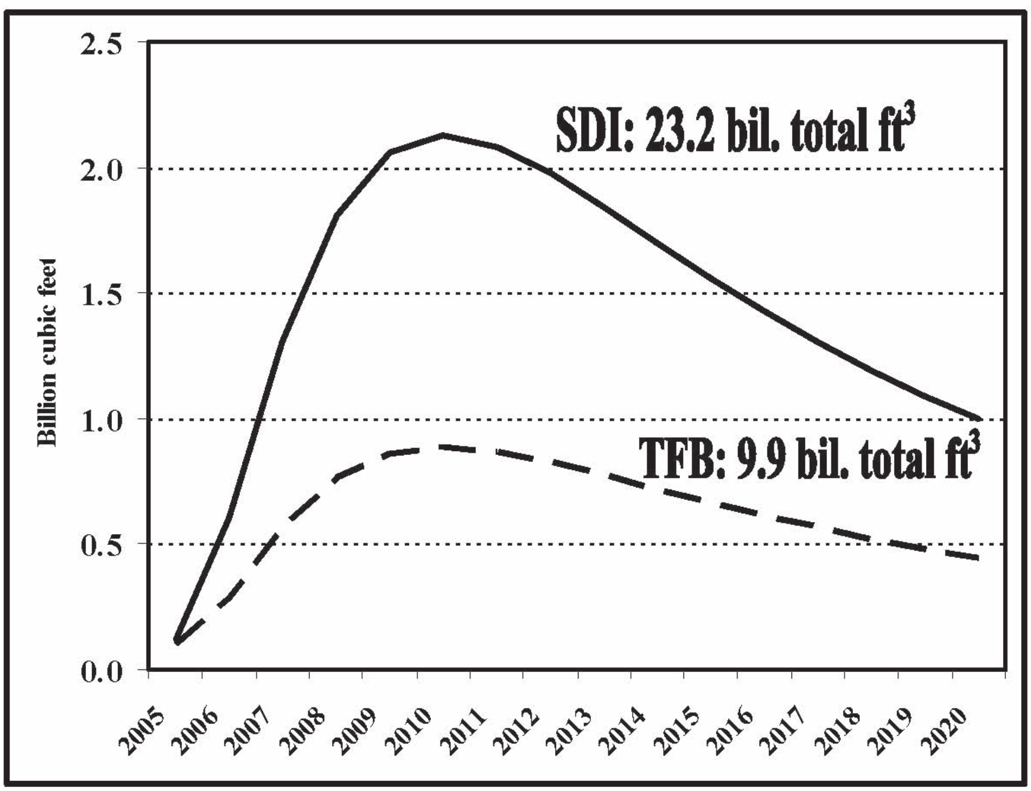

Figure 1—Maximum volume of wood made available annually. SDI, Stand Density Index; TFB, Thinning From Below.

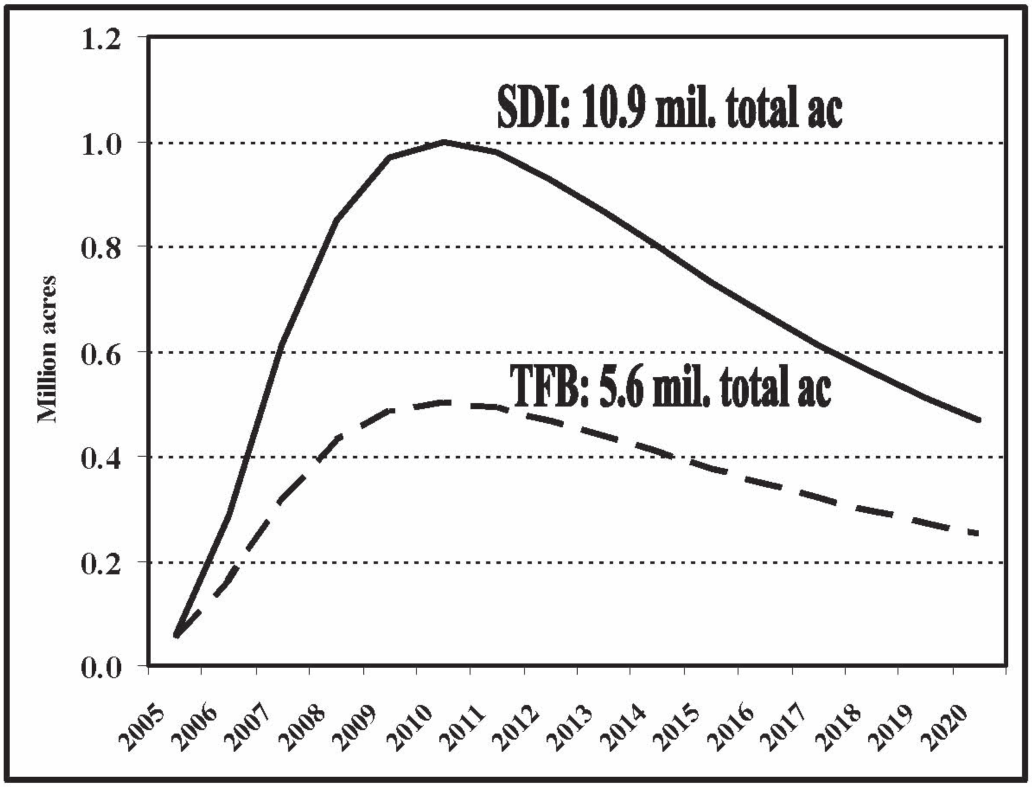

Figure 2—Acres made available annually assuming a constant average volume per acre.

Table 2—Billion cubic feet, million acres, and percentage of total wood available projected to be treated over the 16-year period, 2005 to 2020. SDI, Stand Density Index; TFB, Thinning From Below

Regime		$500/acre admin fee	$200/MCF subsidy
	Billion cubic feet	13.9	17.5
SDI	Million acres	4.7	7.3
	FTE volume (%)	60%	76%
	Billion cubic feet	5.3	8.2
TFB	Million acres	2.4	4.5
	FTE volume (%)	54%	84%

interior regions, this amounted to an increase from 5% to 42% of available wood treated and an average of 2.6 million acres for the SDI program, and 5% to 66% and an average of 2.1 million acres for the TFB program, as a result of dropping the administrative fee and adding the subsidy (figure 3).

In all four scenarios, the total harvest of wood increased when compared to a scenario with no wood available for treatment (figure 4). However, the additional utilization of wood from forest treatments displaced wood utilized from conventional sources (mostly state and private). This crowding out of conventional timber ranges from 5 to 12 billion ft^3 over the 16-year time period, depending on subsidy and thinning regime (figure 5). Over the time

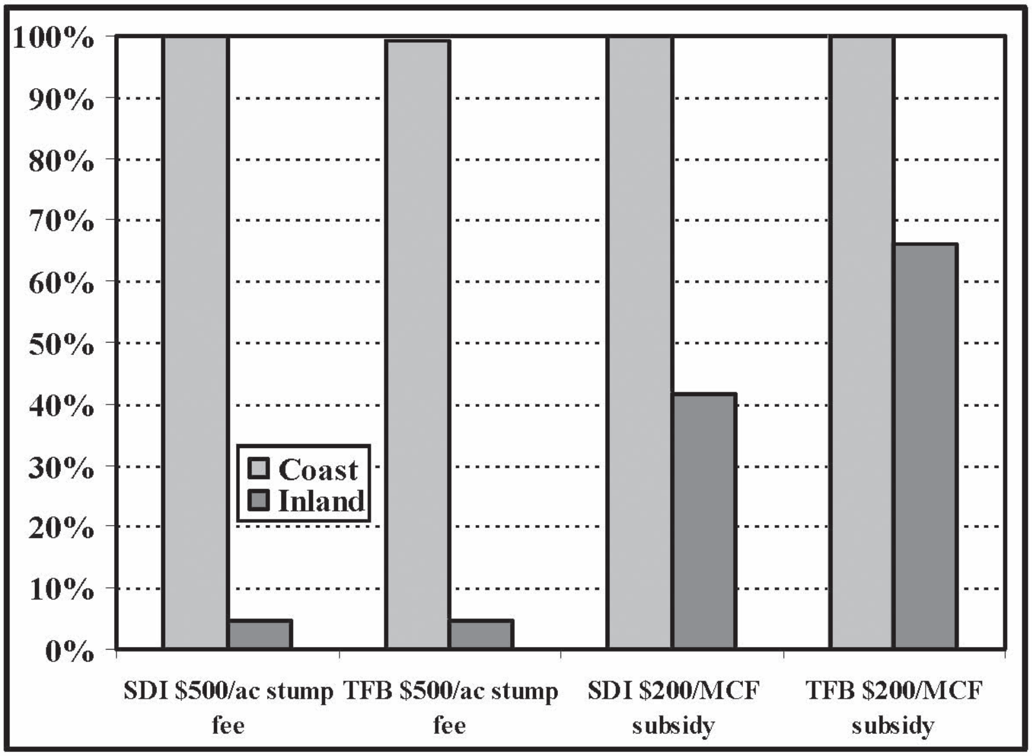

Figure 3—Percentage of available wood utilized. SDI, Stand Density Index; TFB, Thinning From Below.

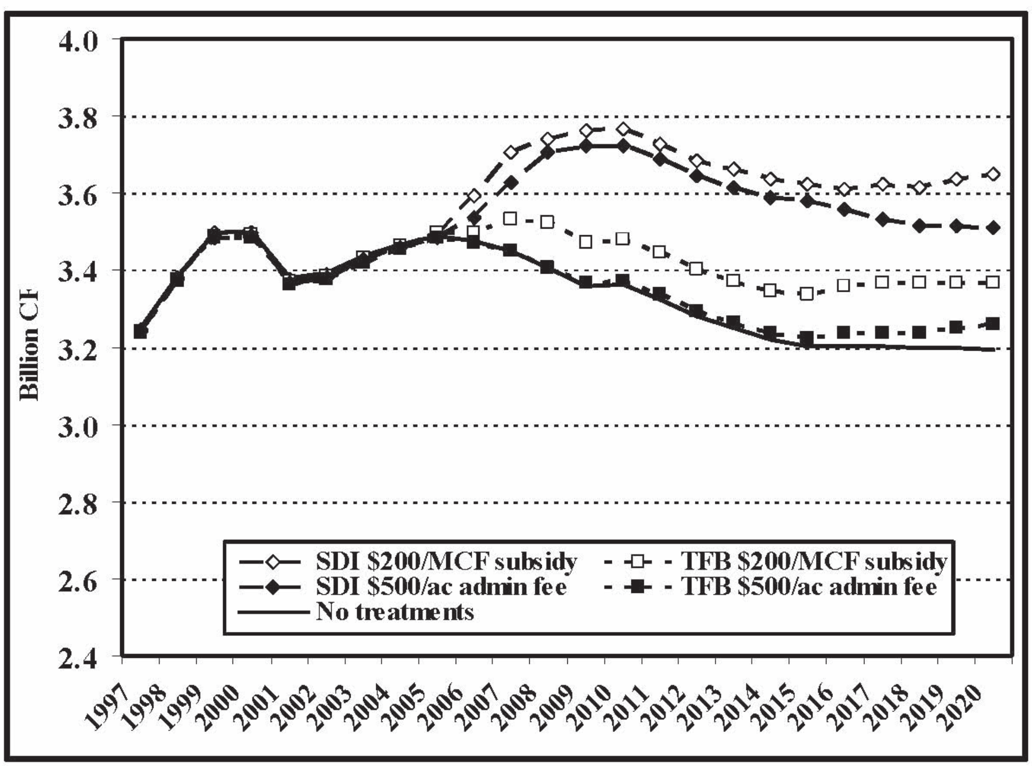

Figure 4—Total volume of wood harvested annually. SDI, Stand Density Index; MCF, per thousand cubic feet; ac, acre.

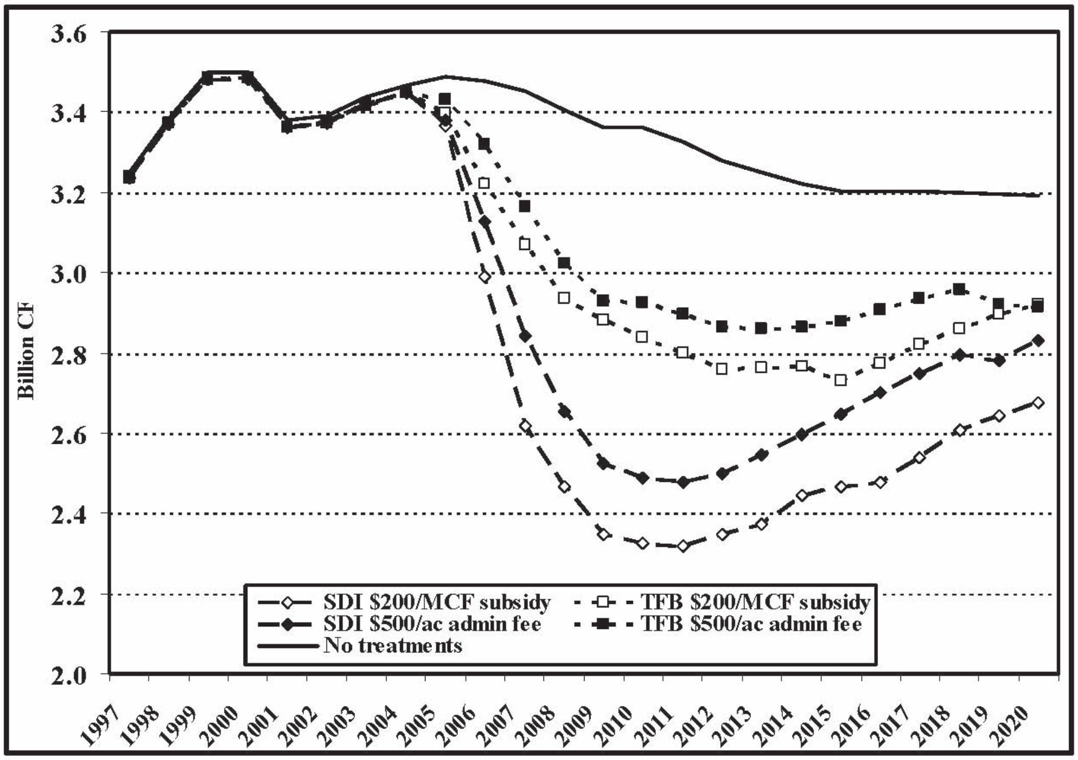

Figure 5—Volume of wood harvested from conventional sources. SDI, Stand Density Index; MCF, per thousand cubic feet; ac, acre.

period, the wood from treatments accounted for an average of 10% to 30% of the total volume of wood harvested, also depending on subsidy and thinning regime. Consequently, the boost in timber supply from thinning and reduction in harvest from conventional supply sources is projected to result in lower timber prices as well (figure 6).

Producer Surplus, Consumer Surplus and Net Welfare

All four scenarios project a decrease in potential revenue to conventional timber suppliers, a loss of producer surplus, which is a direct result of the decrease in regional timber prices and the volume of conventional timber harvested (as compared to a no-treatment scenario). The cumulative potential losses over the 16 year projection period (2005 to 2020) are quite significant, ranging from $34 billion to $70 billion (figure 7).

On the other hand, all four treatment scenarios projected lower wood product prices and increases in wood products consumption resulting in increases in forest product consumer surplus. Over the projection period the cumulative increases ranged from $26 billion to $74 billion (figure 8).

When we observe the changes in cumulative net welfare, defined as the change in producer surplus plus the change in consumer surplus, we see a deviation from the theme of the other results. Both TFB scenarios result in decreasing net welfare totaling as low as –$8.3 billion after 16 years with

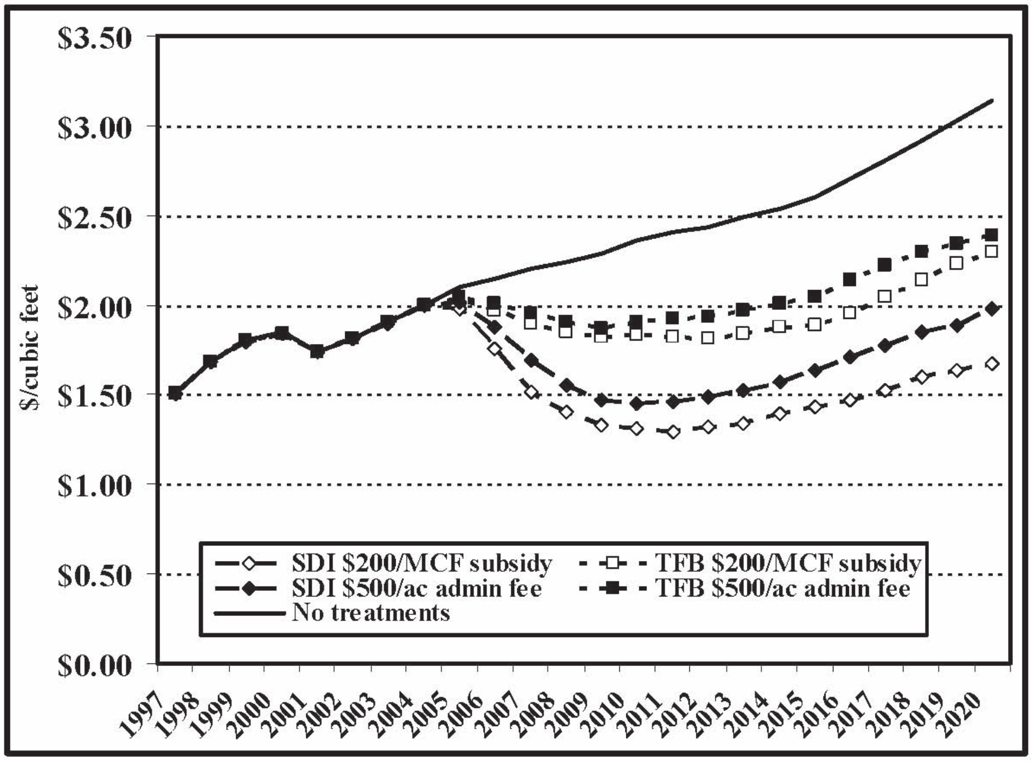

Figure 6—Weighted average softwood timber price in the U.S. West. SDI, Stand Density Index; MCF, per thousand cubic feet; ac, acre.

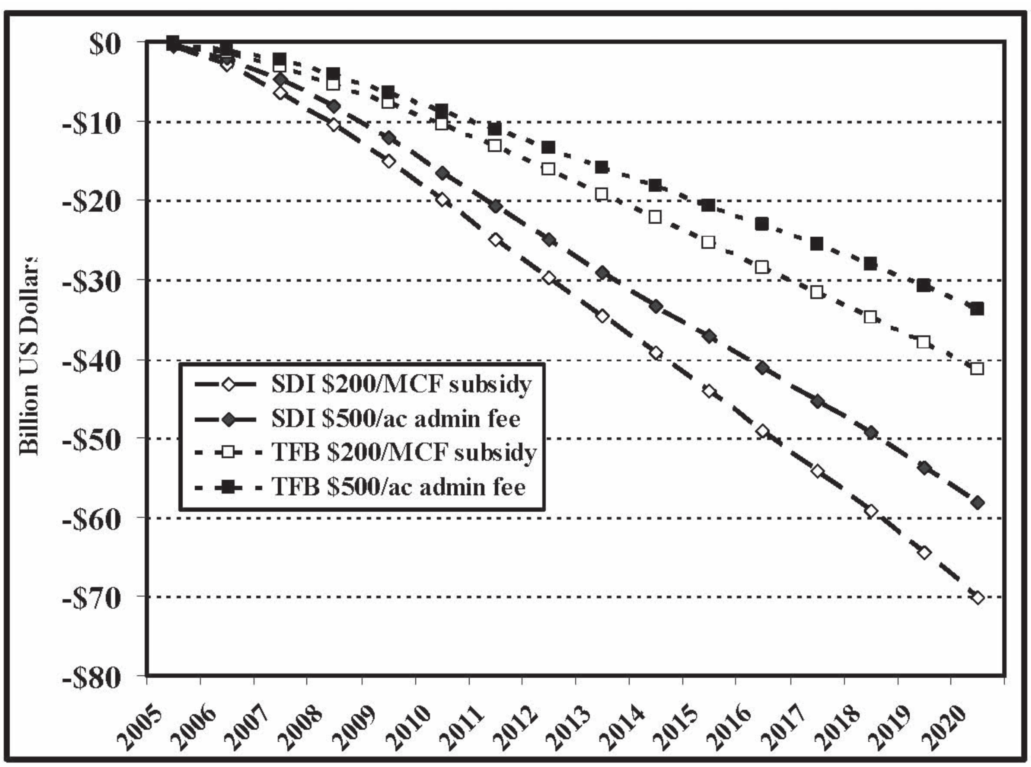

Figure 7—Cumulative change in producer surplus as compared to a no-treatment scenario. SDI, Stand Density Index; TFB, Thinning From Below.

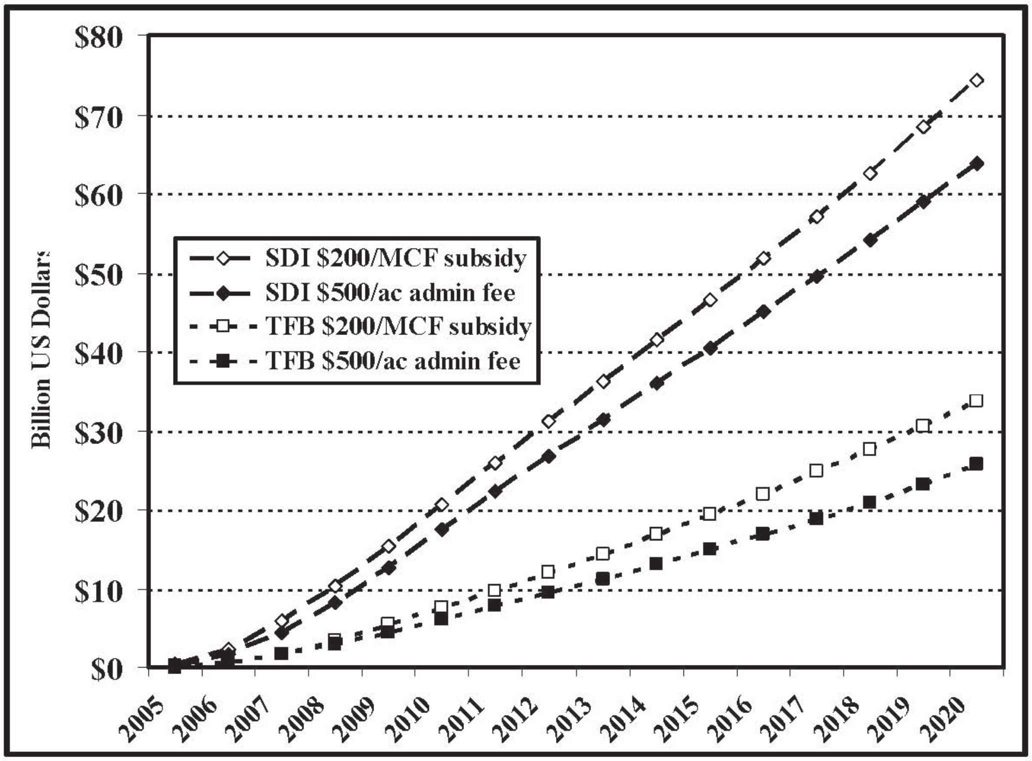

Figure 8—Cumulative change in consumer surplus as compared to a no-treatment scenario. SDI, Stand Density Index; MCF, per thousand cubic feet; TFB, Thinning From Below; ac, acre.

the subsidy making little difference. Conversely, the SDI scenarios show an increasing net welfare and, in fact, the unsubsidized program shows the largest increase in net welfare, $5.7 billion after 16 years (figure 9). This can be seen mainly as a result of the fact that the SDI treatment makes much more high value large timber available than the TFB. This large timber has lower harvest costs, higher product yields, higher output capacity, and lower manufacturing costs (all per volume), and only a model like the FTM-Westthat models these economic complexities of tree and log size class can observe such economic effects. Note that these figures for changes in net welfare do not include a quantification of the effects from reduced fire hazard; they represent only market welfare impacts. The social welfare benefits from reduction in fire hazard are difficult to assess. However, Lippke and others (2006), in their analysis, make a conservative estimate from $1,186/acre to $1,982/acre, increasing with initial fire risk.

Conclusions

We can draw several important conclusions from these results. First, markets would use a substantial volume of wood from fuel treatment programs, even if administrative fees are levied. Second, subsidies for wood from forest treatments seem unnecessary in the coastal region but are crucial to achieve forest treatment goals in the interior region. Third, expanded fuel treatments can have substantial positive impacts on forest product consumer surplus yet negative impacts on revenue to conventional timber sources. Finally, the SDI

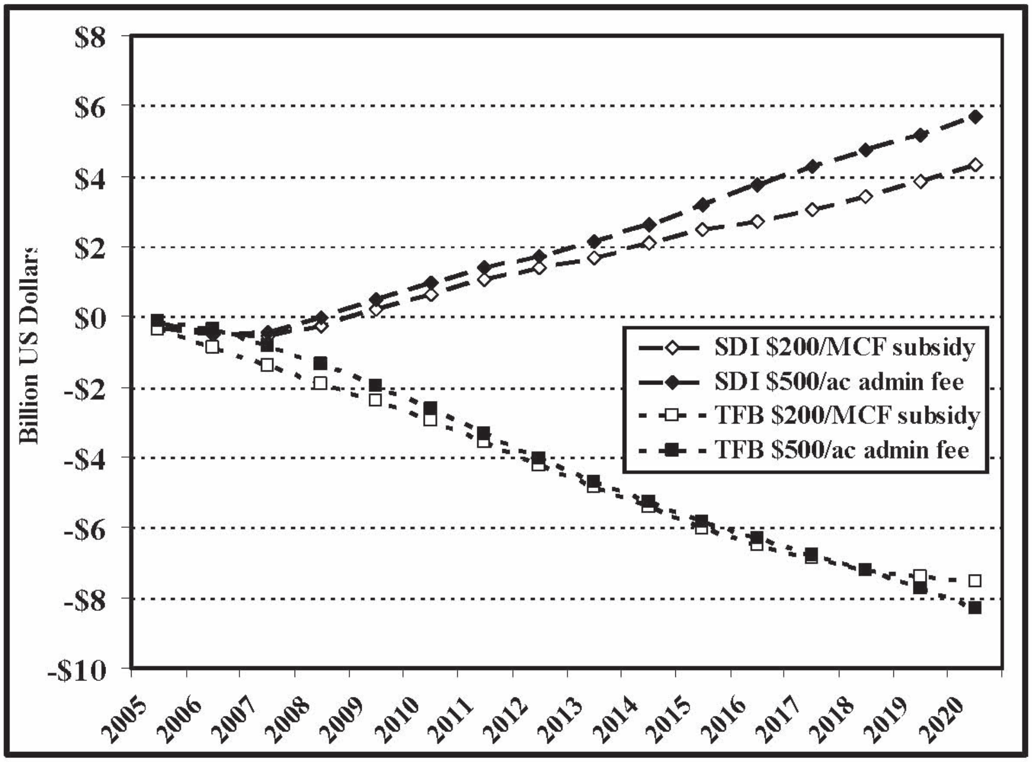

Figure 9—Cumulative change in net economic welfare as compared to a no-treatment scenario. SDI, Stand Density Index; MCF, per thousand cubic feet; TFB, Thinning From Below; ac, acre.

thinning regime can result in potential gains in forest product consumer surplus that more than offset losses in timber producer surplus, resulting in positive net market welfare, while the TFB regime can produce the opposite result (negative net market welfare).

In addition, since the SDI scenarios result in more acres treated and more wood per acre removed, logically they would also result in greater reductions in forest fuels and related fire hazard, producing consequently unambiguously higher net welfare than the TFB scenarios, taking into account both the market welfare and fuel reduction impacts. Other factors should also be considered in judging net welfare, including changes in suppression costs, environmental impacts, wildfire damages, and other less tangible costs and benefits of reduced fire hazard that are addressed, for example, by Lippke and others (2006). All these factors are important when considering policy toward use of thinning treatments that include biomass utilization. In this study, we have focused primarily on the market welfare and fuel reduction impacts.

Acknowledgments

This study was funded in part by the Joint Fire Science Program (JFSP), a partnership of six federal agencies: USDA Forest Service, Bureau of Indian Affairs, Bureau of Land Management, National Park Service, U.S. Fish and

Wildlife Service, and U.S. Geological Survey. Additional in-kind contributions were provided by researchers at the USDA Forest Products Laboratory (FPL) and Forest Service Pacific Northwest Research Station (PNW). Ken Skog of FPL assisted in developing treatment program scenarios for the FTM-Westusing the Fuel Treatment Evaluator (FTE, version 3.0). Henry Spelter of FPL helped estimate conventional stumpage prices, lumber production coefficients, and manufacturing costs. Dennis Dykstra of PNW provided estimates of log and chip volume yields for each tree size class in each of the eight supply regions of FTM–West, based on data from regional wood utilization studies. The study was part of a larger JFSP-funded project, identified as JFSP project 01-1-2-09, "A national study of the economic impacts of biomass removals to mitigate wildfire damages on federal, state, and private lands," coordinated by Jeffrey Prestemon and Karen Lee Abt (Forest Service Southern Research Station). The authors sincerely appreciate the consultation provided by the project coordinators, as well as consultation on the PELPS modeling system from Patti Lebow of the Forest Products Laboratory, additional data input from Matt Alderman of the Forest Products Laboratory, and consultation or input from other members of the JFSP project, including Roger Fight and Jamie Barbour of the Pacific Northwest Research Station and Bob Rummer and Robert Huggett, Jr., of the Southern Research Station.

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Estimating Woody Biomass Supply From Thinning Treatments to Reduce Fire Hazard in the U.S. West

Kenneth E. Skog[1] and R. James Barbour[2]

***Abstract**—This paper identifies timberland areas in 12 western states where thinning treatments (1) are judged to be needed to reduce fire hazard and (2) may "pay for themselves" at a scale to make investment in forest product processing a realistic option. A web-based tool—Fuel Treatment Evaluator 3.0—is used to select high-fire-hazard timberland plots from the Forest Service Forest Inventory and Analysis Program (FIA) database and provide results of simulated thinning treatments. Areas were identified where either torching or crowning is likely during wildfires when wind speeds are below 25 mph. After additional screens are applied, 24 million acres are deemed eligible for treatment (14 million acres on federal lands). Uneven-aged and even-aged silvicultural treatments analyzed would treat 7.2 to 18.0 million of the 24 million acres, including 0.8 to 1.2 million acres of wildland–urban interface area, and provide 169 to 640 million ovendry tons of woody biomass. About 55 percent of biomass would be from main stem of trees ≥7 inches d.b.h. Sixty to seventy percent of the area to be treated is in California, Idaho, and Montana. Volumes and harvest costs from two treatments on the 14 million acres of eligible federal lands are used as inputs to the fuel treatment market model for U.S. West (FTM–West) discussed in these proceedings.*

Introduction

Fire hazard is unacceptably high on many acres of forest land in the U.S. West. For some of these acres, mechanical treatments are a way to reduce fire hazard. A cohesive strategy is needed for identifying the long-term options and related funding needed to reduce fuels (GAO 2005). Given limited government budgets, one approach is to identify places where the use of woody biomass from thinning can best help pay for hazardous fuel reduction treatments and to use this information to aid in allocating funds for all types of hazardous fuel reduction treatments.

We do not attempt to identify all acres in the U.S. West where removal of woody biomass would improve resilience to undesirable fire effects nor did we set out to demonstrate that if this were done enormous volumes of wood materials could be collected. We focus on areas in surface and mixed-severity fire regime forests, where treatments are needed to reduce fire hazard.

For 12 western states (table 1), we selected timberland acres (land capable of producing 20 ft^3/acre/year and not withdrawn from timber utilization) eligible for treatment (determined in part by fire hazard level), applied several alternative silvicultural treatments to reduce hazard while seeking to maintain ecosystem integrity, and evaluated to what extent revenues from the sale of biomass may offset harvest costs. Full results of our study were reported by

In: Andrews, Patricia L.; Butler, Bret W., comps. 2006. Fuels Management—How to Measure Success: Conference Proceedings. 2006 28-30 March; Portland, OR. Proceedings RMRS-P-41. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

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Table 1—Area treated, by state and treatment scenario (million acres).

	Treatments for forest types other than spruce–fir and lodgepole						Treatments for spruce-fir and lodgepole, even-aged in WUI area only	
	Uneven-aged treatments				Even-aged treatments			
	High structural diversity		Limited structural diversity					
State	50% BA removal limit 1A	No BA removal limit 1B	50% BA removal limit 2A	No BA removal limit 2B	50% BA removal limit 3A	No BA removal limit 3B	25% BA removal limit 4A	50% BA removal limit 4B
AZ	0.5	0.5	0.4	0.4	0.1	0.1	0.0	0.0
CA	4.4	4.4	3.8	3.8	1.5	1.5	0.0	0.0
CO	1.2	1.3	1.1	1.1	0.4	0.5	0.1	0.1
ID	2.4	2.5	2.2	2.2	1.1	1.1	0.4	0.4
MT	2.9	3.0	2.5	2.6	1.5	1.6	0.0	0.0
NV	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NM	0.9	1.0	0.8	0.8	0.3	0.3	0.0	0.0
OR	2.2	2.2	1.8	1.8	0.9	0.9	0.0	0.0
SD	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0
UT	0.4	0.4	0.4	0.4	0.2	0.2	0.0	0.0
WA	1.8	1.8	1.5	1.5	0.6	0.6	0.0	0.0
WY	0.3	0.4	0.3	0.3	0.2	0.2	0.0	0.0
Total	17.1	17.5	14.8	15.1	6.7	6.8	0.5	0.5

Skog and others (2006). Results are compared to those from a previous Forest Service assessment (Forest Service 2003).

This evaluation of potential acres to be treated and biomass to be removed is intended to be the first of several evaluation steps:

1. Identify locations across the West where hazardous fuel reduction treatments are needed and that would generate amounts of woody biomass for use that could offset treatment costs.
2. For selected localities in the West, evaluate both current market potential for using wood and prospects for expanding specific markets to use additional wood material.
3. Evaluate the social acceptability of establishing and supporting the infrastructure necessary to use sales of wood as a means for funding fire hazard reduction within the selected areas.

This paper also notes special estimates of biomass supply and treatment costs for two treatments on the 14 million acres of federal lands that are used as inputs to the fuel treatment market model for U.S. West (FTM–West) discussed by Ince and Spelter and by Kramp and Ince in these proceedings. The FTM–West model is used to evaluate the potential impact of increased biomass supply on projected conventional timber supply quantity and timber prices.

The 12 western states have 127 million acres of public and private timberland and 77 million acres of other forest land (Miles 2006a). Although other forest lands have hazardous fuels and wood from treatments that can provide higher value products, the volume and value per acre is very likely to be lower in relation to treatment costs than it is for timberland. Treatments of other forest land may provide an average 7 ovendry tons (odt) of woody biomass per acre (Perlack and others 2005) in the 12 states considered in our study compared with 24 to 34 odt/acre estimated for timberland thinning treatments.

The terms "woody biomass" and "biomass" refer to all wood in all trees—in the main stem, tops, and branches of all sizes of trees. "Merchantable wood" refers to the main stem of all live trees with a diameter at breast height (d.b.h.) ≥5 in., from 1 ft above ground to a minimum 4-inch top diameter outside the bark of the central stem, or to the point where the central stem breaks into limbs and does not include rotten, missing, and from cull.

Methods

Data used were plot-level data from the Forest Inventory and Analysis Program (FIA) of the USDA Forest Service (Smith and others 2004), with additional plot information from the National Forest System (about 37,000 plots in 12 states). The area to be treated and woody biomass to be removed were estimated as if the treatments were to be done within 1 year. In reality, the area treated and amounts removed would extend over many years. Methods were used to simulate treatments on all ownerships, and those results are explained in detail. Methods were also used to simulate treatments on federal land alone, and those results were used to provide biomass amounts and harvest costs to be used in the FTM–West market model.

Screens to Identify Area Eligible for Treatment

Of the 126.7 million acres of timberland in the 12 selected western states (Miles 2006a), 23.9 million acres passed an initial screen and were considered eligible for treatment. A second screen was applied when considering a specific silvicultural treatment, and less than 23.9 million acres actually receive simulated treatment.

Initial Screen—The initial screen was applied to two different groups of forest types: group 1, forest types with surface or mixed-severity fire regimes; and group 2, forest types with high-severity fire regimes. Group 2 includes lodgepole pine and spruce–fir forest types. Group 1 contains all other forest types.

Plots excluded from fire severity group 1 include (a) inventoried roadless areas, (b) counties west of Cascade Mountains in Oregon and Washington, where forests have a long fire return interval, (c) plots with lower fire hazard (both crowning index (CI) and torching index (TI) >25 mph, or CI alone >40 mph). For a map of inventoried roadless areas, see www.roadless.fs.fed.us/maps/usmap2.shtml

Plots excluded from group 2 include (a) all plots outside wildland–urban interface (WUI) areas, (b) inventoried roadless areas, (c) counties west of Cascade Mountains in Oregon and Washington, where forests have a long fire return interval, and (d) plots with lower fire hazard (CI and TI both >25 mph, or CI alone >40 mph).

Selected counties west of the Cascades were excluded because treatments in forests there would be designed to meet objectives other than fire hazard reduction.

Oregon counties excluded were Benton, Clackamas, Clatsop, Columbia, Coos, Curry, Lane, Lincoln, Linn, Marion, Multnomah, Polk, Tillamook, Washington, and Yamhill. Washington counties excluded were Clallam, Clark, Cowlitz, Gray's Harbor, Island, Jefferson, King, Kitsap, Lewis, Mason, Pacific, Peirce, San Juan, Skagit, Snohmish, Thurston, Wahkiakum, and Whatcom.

Of the 126.7 million acres of timberland, 67.5 million acres (53 percent) have lower fire hazard than our criteria. Of the remaining 59.2 million acres, 21.6 million acres (17 percent of all timberland) are in roadless areas or in excluded counties in Oregon and Washington. Of the remaining 37.6 million acres, 13.8 million acres (11 percent of all timberland) are in forest types with high-severity fire regimes, which leaves 23.9 million acres eligible for treatment. In total, our screens removed 81 percent of all timberland and 60 percent of acres with higher fire hazard.

Second Screen—When applying a specific silvicultural treatment, a second screen determined which eligible plots actually receive simulated treatment. Plots were not treated if they would not provide 300 ft^3 of merchantable wood per acre (about 4 odt/acre). Previous studies found that mechanical treatments that produce <300 ft^3 of merchantable wood are unlikely to cover costs of the treatment (Barbour and others 2004, Fight and others 2004).

Fire Hazard Reduction Objectives and Assumptions

Selection of Plots for Treatment—Each FIA plot was assessed for fire hazard by estimating CI and TI (Scott and Reinhardt 2001). Torching index is the 20-ft aboveground wind speed at which crown fire can begin in a specified fire environment; CI is the 20-ft wind speed at which active crown fire behavior is possible (can be sustained) in that environment. Plots were selected for treatment if CI < 25 mph alone or TI < 25 mph and CI < 40 mph (denoted hereafter as CI<25 and TI<25). The focus on crown fires is useful because, although all stands may burn under certain conditions, stands that are likely to burn in crown fires present particular suppression problems, and consequences of crown fires are more severe than those of surface fires. Plots with CI<25 or TI<25 were chosen for treatment because fires might commonly be expected to occur at wind speeds between 15 and 25 mph.

Assumptions for Calculating Torching and Crowning Indexes—Torching and crowning indexes were calculated for each plot based on (a) canopy fuel profile as computed from plot data, (b) slope steepness, (c) selected set of fuel moisture conditions corresponding to "summer drought" conditions (Rothermel 1991), and (d) use of fire behavior fuel model (FM) 9 to represent surface fuels (Anderson 1982).

Fuel model 9 is described as hardwood or long-needle pine litter. It was chosen not because we assume that all surface fuels are hardwood or long-needle pine litter, but because FM 9 results in surface fire behavior mid-range between FM 8 and 10 (other timber litter models) and FM 2 (timber grass model) (personal communication, Paul Langowski, Branch Chief, Fuels and Fire Ecology, USDA Forest Service, Rocky Mountain Region, 2004).

No single fuel model can be expected to adequately represent surface fuels in all timberlands. However, no plot data exist to characterize surface fuels. Assuming more extreme fire behavior, such as FM 10, might lead to recommending thinning where none is really needed, whereas a FM 8, which results in very low-intensity surface fires, may not identify stands at risk of crowning. Fuel model 9 was a compromise.

We also used FM 9 when computing TI and CI after thinning; that is, we assumed that the thinning treatment did not change the surface fuels enough to bump the fuel model into a higher fuel class.

Targets for Crowning and Torching Indexes after Treatment—The fuel hazard reduction objective for each plot was to increase TI and CI to >25 mph or to increase only CI to >40 mph. These objectives are intended either to keep a crown fire from starting or to prevent a crown fire from spreading if crowns are ignited.

Limits on Removal of Basal Area—In some treatment cases, we limited total basal area (BA) removal to keep canopy closure as high as practical. Opening the canopy, while reducing canopy fuels, can lead to different fuel hazard problems: (1) expose surface fuels to solar radiation and wind, which can alter surface fire behavior; (2) increase herbaceous and shrub growth, which may also change surface fire behavior; (3) enhance conifer regeneration, ultimately creating ladder fuels; and (4) increase the risk that remaining trees will be blown down by strong winds.

To the extent that additional objectives call for refinement of our treatments and more removals in local areas, we may be underestimating the amount of area that may be treated with positive average net revenue.

Long-Term Effect of Treatments on Fire Hazard—Forest stands are dynamic, as are forest fuels. The necessary frequency of treatments should be analyzed as part of a much more site-specific planning process, using tools such as FFE–FVS (Reinhardt and Crookston 2003) or fire history studies.

We acknowledge that the fuel hazard reduction treatments described here do not address constraints on land management activities specified in existing land and resource management plans and their potential effects on removals. Nor do these scenarios address the effect on importance of maintaining forest stocking, ground fuels, and other factors that may negatively contribute to CI and TI values on the ecologic health and productivity of forests.

Silvicultural Treatment Objectives and Assumptions—The thinning treatments to reduce fire hazard have an objective to move the stand toward either (1) an uneven-aged condition or (2) an even-aged condition. In addition, the objective of some treatments is to limit BA removed to limit change in stand structure.

Some authors (Graham and others 1999) have suggested that thinning uneven-aged stands in some cases does not reduce fire hazard. We address this concern by designing uneven-aged treatments that take enough trees to be effective in reducing TI, CI, and the risk of crown fire.

Timberland area was divided into forest types that tend to have (1) high-severity fire regimes (where severe fires are routine under natural conditions) and (2) surface or mixed-severity fire regimes. High-severity forest types are excluded from treatments except in WUI areas because severe fires (crown fires) are routine in these forest types under natural conditions, and thinning to avoid severe fire does not support normal fire ecology.

Treatments for Forests with Surface and Mixed-Severity Fire Regimes—Treatments 1A and 1B—uneven-aged, leaving high structural diversity—remove trees so the number of trees remaining in each d.b.h. class after treatment contribute equally toward the numerical value of residual stand density index (SDI) for the stand (Long and Daniel 1990). The final level of overall SDI is adjusted downward by simulated removal of trees across all d.b.h. classes until TI≥25 and CI≥25, or CI≥40. In scenario 1A, removals are limited to 50 percent of initial BA; in 1B, there is no limitation. This scenario results in forest structures that retain high structural diversity with intact understories of small trees.

Restricting removals to <50 percent of the original BA ensures that some semblance of an uneven-aged forest structure is maintained (Alexander and Edminster 1977, Burns 1983).

Treatments 2A and 2B—uneven-aged, limited structural diversity—attempt to achieve TI and CI goals by removing as many small trees as possible while still retaining smaller trees to ensure an uneven-aged structure. The remaining trees in a large d.b.h. class contribute more to the residual stand SDI than do trees in a smaller d.b.h. class.

The level of overall SDI is adjusted downward by simulated removal of trees until the target TI and CI values are reached (treatment 2B) or until 50 percent of the original BA has been removed (treatment 2A).

Treatments 3A and 3B—even-aged, thin from below—emulate intermediate thinning in an even-aged silviculture system where the intent is to ultimately harvest and replace the existing forest. Small trees are completely removed in successively larger d.b.h. classes until CI and TI goals are met (treatment 3B) or until 50 percent of the original BA has been removed (treatment 3A). Thinning more than 50-percent BA may fundamentally alter the character of the forest and should not be prescribed without careful consideration of all potential ecosystem effects.

Treatments for Forests with High Severity Fire Regimes—Treatments 4A and 4B—even-aged, thin from below (spruce–fir and lodgepole pine forest types)—are similar to treatments 3A and 3B, except BA removals are restricted to 25 percent of existing stocking (treatment 4A) or 50 percent of existing stocking (treatment 4B) and *are only in WUI areas.* The 25-percent removal restriction is based on published partial cutting guidelines and is necessary to avoid wind throw in shallow-rooted tree species such as spruce, fir, and lodgepole pine (Alexander 1986a,b).

Harvest Costs and Product Revenue Estimation

The cost to provide biomass ready for transport at the roadside was estimated for each plot using the Fuel Reduction Cost Simulator (FRCS) from My Fuel Treatment Planner (Biesecker and Fight 2006, Fight and others 2006). Cost estimates are made for up to eight harvesting systems, based on the number and average volume of trees in various size categories and the slope of the site. Ground-based harvesting systems include (a) manual-felling log-length system, (b) manual-felling whole-tree (WT) system, (c) mechanized-felling WT system, and (d) cut-to-length (CTL) system. Cable-yarding systems include (a) manual-felling log-length system, (b) manual-felling WT system, (c) manual WT/log-length system, and (d) CTL system.

The cost for the least expensive suitable system was assigned to each plot. We assumed that (1) harvest is only a partial cut, (2) tops and branches are collected for use when the low-cost system brings whole trees to the landing, (3) trees down to 1 inch d.b.h. are removed, (4) average distance that logs are moved from stump to landing is 1,000 ft, (5) average area treated is 100 acres, and (6) distance to move equipment between harvest sites is 30 miles. Costs might be reduced if small d.b.h. trees are not removed from the site and treated by another method (e.g., pile and burn).

We assume the product values and hauling costs used in the 2003 Assessment. Actual prices will vary by location and over time.

Delivered sawlogs (volume from main stem ≥7inches d.b.h.)	$290/10^3 board feet
Delivered chips (volume from wood and bark <7 inches d.b.h., tops and branches of larger trees)	$30/odt
Haul distance	100 miles
Haul cost (for both sawlogs and chips)	$0.35/odt/mile

The Fuel Treatment Evaluator 3.0 (FTE), a web-based tool available for general use, was used to select areas for treatment, apply treatments to FIA plot data, and generate removal information and maps (Miles 2006b).

Findings

Area Treated and Biomass Removed

The 2003 Assessment identified 96.9 million acres of timberland for possible thinning in fire regime condition classes (FRCCs) 1, 2, and 3, with 28.5 million acres in FRCC 3. The 2003 Assessment selected plots for treatment if timber density, as measured by SDI, was greater than 30 percent of the maximum SDI for the plot forest type.

FRCC refers to the degree to which the current fire regime (including fire recurrence, intensity, severity) is different from the historical pattern, with FRCC 3 having the most divergence (see definitions at http://ncrs2.fs.fed.us/4801/fiadb/fire_tabler_us/rpa_fuel_reduction_treatment_opp.htm).

In contrast, our treatments 3A (all group 1 forest types) and 4A (group 2 forest types in WUI areas) together would treat 7.2 million acres, and treatments 1B and 4B together would treat 18.0 million acres, with 85 percent of acres in FRCCs 2 and 3.

Of the 21.2 million WUI acres identified in 12 western states (Stewart and others 2003), an estimated 4.1 million acres are in timberland. For the high-severity types, 0.5 million acres of WUI were included in treatments 4A or 4B (table 1). For all other forest types, 0.3 to 0.7 million acres of WUI were included in treatments 1A to 3B. So the total WUI area to be treated could be 0.8 to 1.2 million acres, or 20 to 30 percent of the timberland WUI acres. We could be underestimating area to the extent that communities decide to treat larger WUI areas.

Treatment 1B would thin the largest area—17.5 million acres, or about 14 percent of all timberland in the 12 western states. The highest percentage of timberland to be treated would be in California (33 percent), followed by New Mexico (24 percent), Idaho (21 percent), Montana (21 percent), and Arizona (16 percent).

The 2003 Assessment identified total possible removal of 2.1 billion (10^9) odt biomass with treatment of all 94.5 million acres of treatable timberland. Removal from 66.3 million FRCC 2 and FRCC 3 acres could provide 1.5 billion odt of biomass. If only 60 percent of FRCC 3 acres are treated (17.1 million acres), the yield would be 346 million odt of biomass.

In our assessment, we identified 7.2 to 18.0 million acres for treatment that would yield 169 million odt (smallest amount) from treatments 3A and 4A and 640 million odt (largest amount) from treatments 1B and 4B (tables 1 and 2).

The distribution of biomass removed by tree size differs greatly between the uneven-aged and even-aged treatments (table 3). In addition, the distribution for the uneven-aged treatments differs substantially from the results of the uneven-aged treatment used in the 2003 Assessment. The 2003 Assessment showed the most biomass removed from the 10-inch d.b.h. class. In contrast, our uneven-aged treatments provide most biomass in the ≥21-inch d.b.h. classes. Our uneven-aged treatments remove more because residual SDI for our treated stands is <20 percent of maximum SDI, compared with 30 percent of maximum in the 2003 Assessment. Thinning to an average 20 percent of maximum SDI is needed in our assessment to thin to achieve CI>40 when we cannot attain TI>25. We could help attain TI>25 rather than having to reach CI>40 by pruning branches to raise canopy base height and by decreasing surface fuels.

In our assessment, the proportion of all acres treated and biomass removed that comes from National Forest or all Federal land is about 55 or 60 percent, respectively, for both even-aged and uneven-aged treatments.

Fire Hazard Reduction Outcomes

Four possible fire hazard reduction outcomes were identified for the 23.9 million acres eligible for treatment:

1. Treatment is applied; both CI>25 and TI>25.
2. Treatment is applied; CI>40.
3. Treatment is applied; 50-percent BA removal limit is achieved before achieving either (1) or (2).
4. No treatment is applied; <300 ft^3 of merchantable wood could be removed.

Uneven-aged treatments with the 50-percent BA removal limit (1A and 2A) treat 71 and 61 percent of eligible acres, respectively. These treatments reach the medium or high hazard reduction goal for 44 and 30 percent of eligible

Table 2—Initial standing biomass and biomass removals from this assessment (million ovendry tons).

		Treatments for forest types other than spruce–fir and lodgepole						Treatments for spruce-fir and lodgepole, even-aged in WUI area only	
		Uneven-aged treatments				Even-aged treatments			
		High structural diversity		Limited structural diversity					
State	Initial volume on treatable timberland	50% BA removal limit 1A	No BA removal limit 1B	50% BA removal limit 2A	No BA removal limit 2B	50% BA removal limit 3A	No BA removal limit 3B	25% BA removal limit 4A	50% BA removal limit 4B
	million acres								
AZ	29.5	11.0	13.1	8.9	9.9	2.3	2.6	0.1	0.1
CA	419.2	219.5	222.4	144.8	145.2	37.4	40.1	0.2	0.3
CO	49.3	20.6	28.4	17.4	21.8	6.0	7.5	0.8	1.4
ID	171.4	68.1	83.1	57.7	63.4	26.6	29.4	6.4	10.5
MT	166.7	66.8	84.4	58.9	69.2	36.5	41.9	0.1	0.2
NV	0.9	0.3	0.3	0.2	0.2	0.1	0.1	0.0	0.0
NM	41.9	18.3	24.1	15.0	18.4	5.5	6.3	0.0	0.0
OR	210.4	76.8	88.7	53.9	56.2	25.5	26.3	0.0	0.0
SD	3.9	1.3	1.4	1.1	1.1	0.3	0.3	0.0	0.0
UT	18.2	7.5	9.8	6.9	8.0	2.9	3.2	0.0	0.1
WA	128.7	50.0	60.9	38.8	42.4	14.9	15.4	0.0	0.0
WY	17.7	7.5	10.3	7.3	8.9	3.6	4.5	0.1	0.2
Total	1,257.7	547.8	626.8	410.8	444.7	161.6	177.5	7.6	12.8

Table 3—Biomass removal by treatment and tree d.b.h. class (tons per acre).

	Treatments for forest types other than spruce–fir and lodgepole						Treatments for spruce-fir and lodgepole, even-aged in WUI area only	
	Uneven-aged treatments				Even-aged treatments			
	High structural diversity		Limited structural diversity					
d.b.h. class	50% BA removal limit 1A	No BA removal limit 1B	50% BA removal limit 2A	No BA removal limit 2B	50% BA removal limit 3A	No BA removal limit 3B	25% BA removal limit 4A	50% BA removal limit 4B
(in.)								
2.0	0.4	0.5	0.5	0.6	0.8	0.9	0.4	0.5
4.0	1.2	1.5	1.5	1.7	2.2	2.4	1.5	2.2
6.0	2.1	2.4	2.8	3.0	4.9	5.1	4.9	5.4
8.0	2.9	3.3	3.6	3.8	6.2	6.5	4.8	6.6
10.0	3.1	3.6	3.6		2.5	2.8	0.7	2.1
14.0	2.5	2.8	2.2	2.4	1.2	1.4	0.4	0.9
16.0	1.9	2.2	1.5	1.6	0.6	0.8	0.4	0.8
18.0	1.4	1.7	0.9	1.0	0.4	0.5	0.0	0.2
20.0	1.0	1.2	0.4	0.5	0.3	0.3	0.0	0.0
22+	12.5	13.2	7.6	7.7	0.7	0.6	0.0	0.0
Total	32.0	35.8	27.7	29.5	24.2	26.0	16.6	24.5

acres, respectively (table 4). When the BA limit is removed (1B and 2B), a slightly greater percentage of acres is treated (72 and 62 percent, respecively), all reach a hazard reduction target, and biomass removal increases 14 percent (548 to 627 million odt) and 8 percent, respectively.

The even-aged treatment with the 50-percent BA removal limit (3A) treats 28 percent of all eligible acres but reaches the medium or high hazard reduction goal for only 7 percent of the eligible acres (table 4). When the 50-percent limit is removed (3B), 28 percent of acres are treated and all these treated acres reach the medium or high hazard reduction goal. Moving from treatment 3A to 3B requires a 10-percent increase in biomass removals, which includes the biomass from the additional 1 percent of acres treated.

In general terms, for forest area where there is the need to obtain a minimum level of merchantable wood to yield positive average net revenue and a restriction on BA removal, our results suggest that the uneven-aged treatment would more likely achieve one of the hazard reduction targets than would an even-aged treatment—in our example, 44 percent or 30 percent, compared with 7 percent.

If raising TI is a priority, then even-aged treatments are more effective than uneven-aged treatments. However, even-aged treatments are less likely to produce 300 ft^3 of merchantable wood and provide positive net revenue from sale of products.

Treatment Costs, Product Revenues, Net Revenues

Average treatment costs per acre for even-aged treatments are about the same as for uneven-aged treatments for the acres selected for each treatment, though fewer acres are selected for even-aged treatments because fewer acres are able to provide 300 ft^3/acre.

Table 4—Fire Hazard outcomes (percentage of treatable acres).

	Goal attainment						
Treatment	Low (50% BA limit is reached) (treatment is made but BA limit is reached)	Medium CI>40 only	High CCI&TI >25	Total achieving a medium or high target	Total receiving some treatment	Not treated (provides less than 300 ft^3 merchantable wood/acre)	Total
1A	28	21	22	44	71	29	100
2A	31	18	12	30	61	39	100
3A	21	4	3	7	28	72	100
1B	0	23	49	72	72	28	100
2B	0	14	48	62	62	38	100
3B	0	6	22	28	28	72	100

Average net revenues per acre are positive without subsidy for all treatments on gentle slopes and for uneven-aged treatments 1A, 1B, and 2B on steep slopes (table 5). With a $20/green ton subsidy for chips, average net revenues per acre are also positive for uneven-aged treatments 2A and for even-aged treatment 3B on steep slopes. Even with a subsidy, even-aged treatment 3A on steep slopes incurs a net cost per acre. With the subsidy, we could relax the 300-ft^3 merchantable wood requirement for all treatments on gentle slopes and still attain positive average net revenue.

Treatment Costs—The estimated cost to harvest and move biomass to the roadside is less than $1,000/acre for about 50 percent of acres treated for all treatments except treatment 4A, for which estimated costs are lower. Acres on gentle slopes (≤40 percent) tend to cost less, and acres on steep slopes (>40 percent) cost more.

Even though the even-aged treatments call for more trees to be harvested per acre on average, harvesting cost per acre is lower than or about the same as for uneven-aged treatments, which harvest fewer trees. This may be explained in part by the fact that we selected the lowest cost harvesting system for each plot analyzed. Costs for even-aged treatments would also be kept low by the requirement to provide a certain volume in larger trees to provide 300 ft^3/acre.

Biomass Revenues—The estimated delivered value of biomass per acre varies from $1,600 to $,2600, excluding treatments 4A and 4B, if the main stem volume of trees ≥7 in. d.b.h. goes to higher value products and the remainder is delivered as fuel chips. If all volume goes for chips, the delivered value varies from $430 to $640/acre.

For uneven-aged treatments 1A and 1B, about 67 percent of biomass is merchantable wood from trees ≥7 in. d.b.h. For even-aged treatments 3A and 3B, about 50 percent of biomass is merchantable wood from trees ≥7 in. d.b.h. Also, biomass removed per acre is greater for treatments 1A and 1B than for treatments 3A and 3B. As a result, if merchantable wood goes to higher value products, the revenue from the uneven-aged treatments 1A and 1B is $800 to $1,200/acre more than for even-aged treatments 3A and 3B. If all wood goes for chips, treatments 1A and 1B provide only $50 to $100 more per acre than do treatments 3A and 3B.

Table 5—Estimated treatment costs, and revenuesa minus fuel treatment costs when larger diameter logs are sold for higher value products or for chips.

	Average treatment cost ($/acre)		Net revenue (cost) with merchantable wood used for higher value products ($/acre)		Net revenue (cost) with merchantable wood used for chips ($/acre)		Net revenue (cost) with merchantable wood used for higher value products and chips given a subsidy of $20 per green ton ($/acre)	
Treatment	Slope ≤40%	Slope >40%	Slope ≤40%	Slope >40%	Slope ≤40%	Slope >40%	Slope ≤40%	Slope >40%
1A	903	1,774	619	(256)	(1,064)	(1,933)	1,039	163
2A	844	1,831	343	(453)	(978)	(1,867)	757	(32)
3A	854	1,966	(112)	(833)	(973)	(1,882)	391	(368)
4A	692	1,811	(144)	(726)	(766)	(1,550)	202	(478)
1B	986	1,839	686	(9)	(1,161)	(1,917)	1,159	479
2B	882	1864	356	(120)	(1,023)	(1,909)	798	114
3B	902	1975	(86)	(762)	(1,024)	(1,892)	441	(255)
4B	952	1,822	(18)	(266)	(1,073)	(1,615)	421	36

[a] Product value assumptions: delivered sawlog value, $290/mbf; delivered chip value, $30/od ton; transport cost, $0.35/od ton; haul distance, 100 miles.

Net Revenue (Costs) from Treatments—Average net revenue from uneven-aged treatments is positive for gentle slopes ($340 to $690/acre) and negative for steep slopes (–$9 to –$450/acre). Average net revenue for even-aged treatments is $400 to $700 less than that for uneven-aged treatments in the same slope category (table 5). Net revenues for treatments on steep slopes are least negative for uneven-aged treatments 1B and 2B (–$9 and –$120/acre, respectively).

In comparison to the uneven-aged treatment analyzed in the 2003 Assessment, our uneven-aged treatments (1A, 1B, 2A, 2B) provide about the same net revenue per acre for sites with gentle slopes ($350 to $700/acre). For steep slopes, however, our net revenue per acre is about $700 less and negative, whereas the estimates from the 2003 Assessment are positive. This difference could be due to the difference in plots selected.

If a subsidy of $20/green ton is provided for chips delivered to a mill, then the net revenue is positive for all treatments on gentle slopes and uneven-aged treatments 1A, 1B, and 2B (table 5). For these treatments and revenues, we could relax the requirement for 300 ft^3/acre and treat more acres.

Biomass Removal Maps—Areas where biomass removal from thinning on timberland is most likely to provide net revenues per acre include northern California, northern and central Idaho, western Montana, central and northern Oregon, and Washington. Smaller acreages include central to southern Colorado, central/east Arizona, and northern New Mexico. The timberland in WUI areas receiving simulated treatment is found primarily in northern California, northern Idaho, western Montana, western Washington, and central Colorado (figs. 1 and 2).

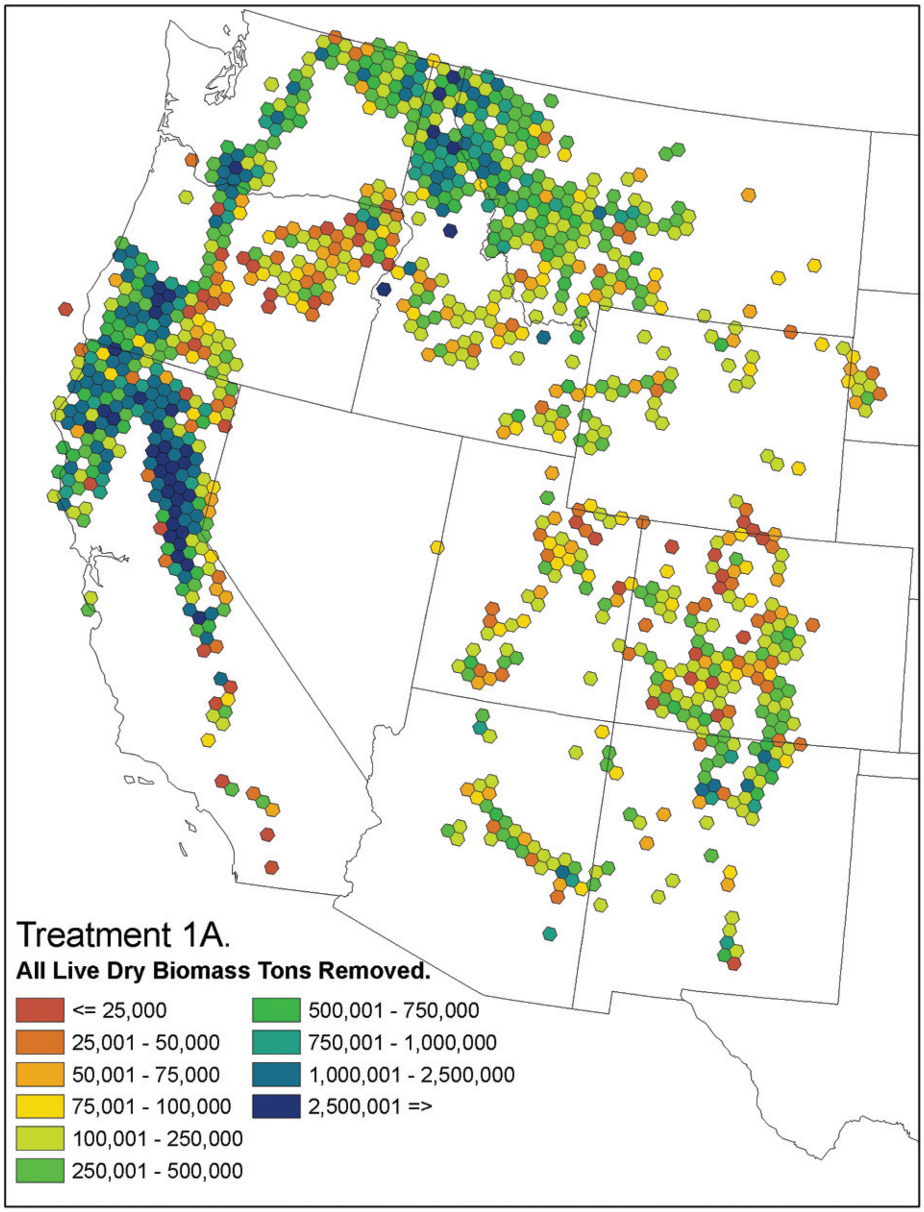

Figure 1—Total biomass removed per 160,000-acre area for uneven-aged treatment 1A (tons).

Estimates of Biomass Removed and Harvest Costs Used in the FTM–West Model

Two sets of treatments were applied to the 14 million acres of federal timberland judged eligible for treatment. These are treatments 1A and 4A and treatments 3A and 4A. Volumes and harvest costs from these treatments are used as inputs to the FTM–West market model described by Ince and Spelter and by Kramp and Ince in these proceedings. Unevenaged treatments 1A and 4A combined (SDI treatment) treat 10.9 million acres and provide 347 million tons (23.2 billion ft^3) at an average cost of $1,531/acre ($0.719/ft^3). Even-aged treatments 3A and 4A combined (TFB treatment) treat 5.6 million acres and provide 148 million tons (9.9 billion ft^3) at an average cost of $1,420/acre ($0.807/ft^3).

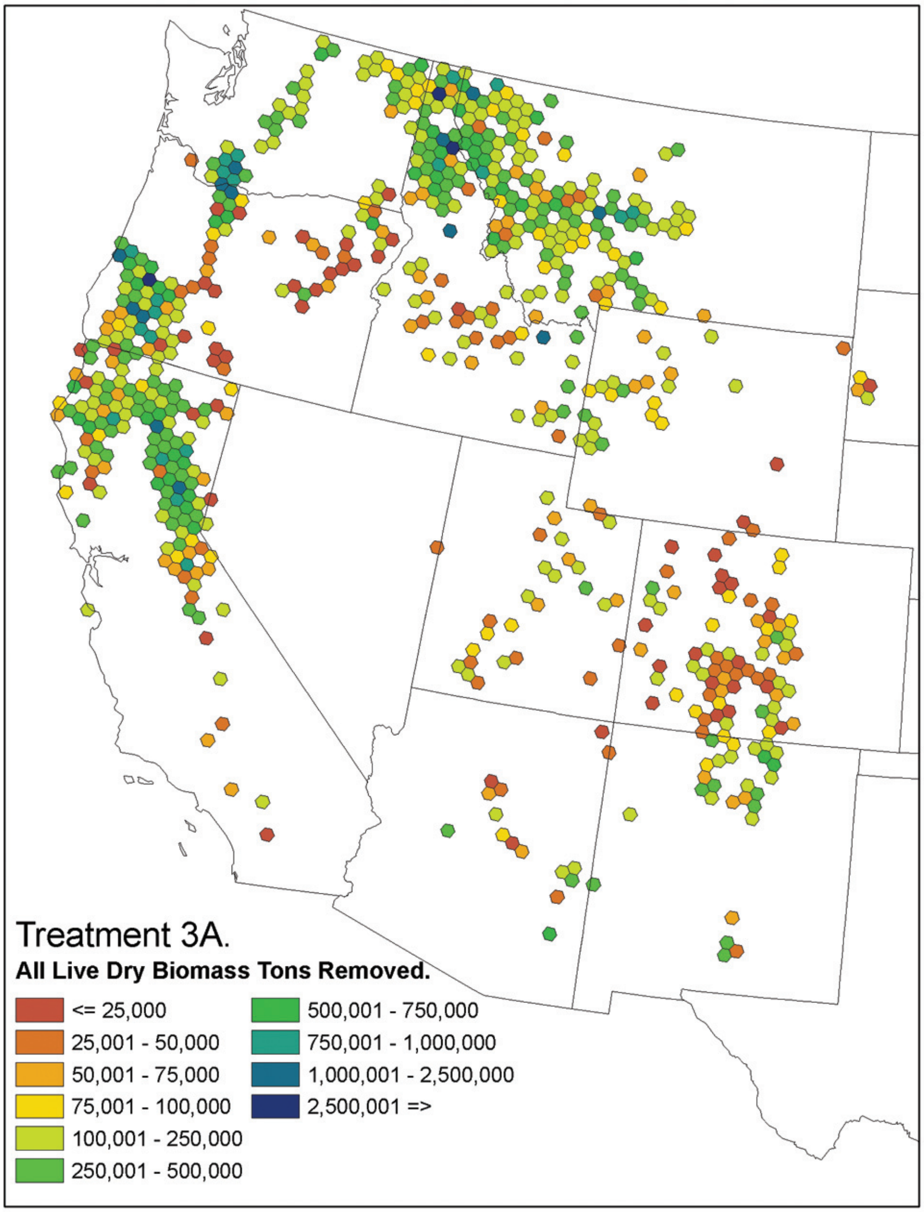

Figure 2—Total biomass removed per 160,000-acre area for even-aged treatment 3A (tons).

Summary

The proportion of the 23.9 million eligible acres that can be thinned and provide positive net revenue from the sale of biomass products varies substantially, depending on whether an even- or uneven-aged silvicultural treatment is used and whether removals are limited or not limited to taking 50 percent of initial BA.

Under our assumptions, uneven-aged treatments will be able to treat a higher proportion of acres with resulting positive net revenue than will even-aged treatments. Moreover, for treated acres, if BA removal is limited to 50 percent limit, then uneven-aged treatments are more likely to attain one of our hazard reduction targets (CI>25 and TI>25, or TI>40) than are the even-aged treatments.

Both uneven-aged and even-aged treatments are able to meet hazard reduction targets on all acres if we remove the BA removal limits and the requirement to provide 300 ft^3/acre of merchantable wood. But the hazard reduction benefit of removing the BA limit may be limited or offset by the effect of a more open canopy and more greatly altered stand structure. The data on costs and revenues suggest that if uneven-aged treatments were used everywhere, revenues could cover a notably higher proportion of costs than if even-aged treatments were used everywhere.

If we assume a $20/green ton subsidy for chips, average revenue is positive for all treatments on gentle slopes and increases the most for even-aged treatments (about $500/acre) because they provide the most chips. Revenue for uneven-aged treatments increases about $410/acre.

The eligible acres and treated acres are predominately in California, Idaho, and Montana, which include 65 to 70 percent of the treated acres for both uneven-aged and even-aged treatments. There are an estimated 21.2 million acres of WUI area in the 12 western states studied, of which an estimated 4.1 million acres is timberland. Treatments would cover 20 to 30 percent of this timberland

Given the concern about removing large trees by uneven-aged thinning, it may be possible to reduce large tree harvest by pruning or reducing surface fuels to increase torching index rather than thinning to reach a high crowning index. Supplementary treatments are likely to increase harvest costs and decrease net revenue per acre.

Acknowledgments

This paper is an outcome of the Wood Utilization Opportunity Areas (WUOA) Project that was funded in part by the National Fire Plan Research Program (Project 02.FPL.C.1). The project is a collaborative effort of USDA Forest Service researchers and managers including Ken Skog, Forest Products Laboratory, and Jamie Barbour, Pacific Northwest Research Station, co-team leaders; Roger Fight, research forest economist (retired), Pacific Northwest Research Station; Karen Abt and Bobby Hugget, research economists, Southern Research Station; Frank Burch, silviculturist, Washington, DC; Pat Miles, research forester, North Central Research Station; Elizabeth Reinhardt, project leader, Rocky Mountain Research Station; and Wayne Sheppard, research silviculturist, Rocky Mountain Research Station.

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Biomass Utilization Modeling on the Bitterroot National Forest

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Abstract—*Utilization of small-sized wood (biomass) from forests as a potential source of renewable energy is an increasingly important aspect of fuels management on public lands as an alternative to traditional disposal methods (open burning). The potential for biomass utilization to enhance the economics of treating hazardous forest fuels was examined on the Bitterroot National Forest and surrounding areas. Initial forest stand conditions were identified from Forest Inventory and Analysis (FIA) data. The Forest Vegetation Simulator (FVS) was used to simulate stand growth and development and estimate removed volumes. Harvest and haul cost models were used to estimate stump to mill costs and these were integrated into MAGIS, a natural resources decision-support system. Temporal and spatial implications of utilization were examined through optimization modeling with MAGIS to identify sustainable quantities and associated costs based on accessibility, haul distance, flow, and quantity of small-diameter material. This study enables land managers, investors, and policy-makers to make informed economic and environmental decisions regarding biomass as a renewable energy source in the Bitterroot National Forest area and will serve as a model for biomass utilization in other areas.*

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Introduction

In the western U.S. there are approximately 15.8 million acres of accessible forestland that could benefit from mechanical fuel treatments to reduce hazardous fuels and disastrous effects of severe wildfires (USFS 2003). Mechanical treatments will produce significant quantities of currently sub- and non-merchantable biomass material not suitable for lumber or pulp production that must be disposed to avoid leaving hazardous fuels in the forest. Traditionally, this biomass has been disposed onsite by burning, which has drawbacks such as potential escape, air quality issues and limited burning windows.

Research has indicated that fuel treatments on public lands have the potential to produce an abundance of biomass (Barbour and others 2004, USDOI Unpublished, USFS 2003), but competitive markets for this material are generally lacking. However, gaining popularity, momentum, and financial feasibility is utilization of this traditional waste material for renewable energy production, specifically, thermal energy production at relatively small scales in rural areas throughout the Western U.S. With the establishment of the Fuels for Schools Program, a collaboration of federal and state agencies providing financial subsidies and incentives, small scale thermal energy production facilities are now being constructed (www.schoolsforfuels.org). Other potential uses of biomass are also being investigated (LeVan-Green and Livingston 2003). Thus, outlets for biomass are forming, providing an alternative to onsite burning.

This paper compares the economic tradeoffs between biomass recovery from fuel treatment for renewable energy production and biomass disposal by open burning in Ravalli County, Montana. We have integrated fuel treatments devised with Bitterroot National Forest personnel with several independent and exogenous models to develop a set of biomass disposal alternatives. These alternatives reflect realistic choices managers must make when determining if biomass utilization for renewable energy production is economically justified or if onsite burning may be the best option. From this notion of alternative disposal options, we have devised a spatial and temporal model of biomass utilization economics based on site distance from a utilization center.

Methods

Study Area

The location specified for this analysis – the Bitterroot National Forest in western Montana – was chosen due to a number of economic and environmental factors it has in common with other communities in the inland western U.S. The area has an abundance of National Forest land, a growing population particularly in the Wildland Urban Interface (WUI), and contains a significant amount of forestland categorized as moderately to highly removed from historical wildfire regimes (USFS 2003b). Furthermore, this area is within proximal distance of a modest amount of existing wood products infrastructure with biomass utilization capacity. These include two recently established, small-scale facilities within the study area capable of utilizing biomass for thermal energy, and in adjacent Missoula county to the North, a sawmill and a pulpmill that utilizes biomass as hogfuel.

Silvicultural Treatments Selected for the Bitterroot National Forest

A wide variety of silvicultural treatments are available to land managers to achieve differing fuel treatment objectives. In this analysis we focused on mechanical treatments designed to reduce wildfire effects and restore forests to sustainable and historical conditions, where prescribed burning would not be feasible under present conditions. Discussions with Bitterroot National Forest (BNF) silvicultural and fire management personnel yielded the following three prescriptions:

1) **Thin from below (TB9)** – cut and remove all trees up to a 9 inches diameter breast height (d.b.h.); apply this prescription only to stands having 1) basal area (BA) greater than 50 ft^2/ac for trees greater than 9 inches d.b.h., or 2) BA greater than 20 ft^2/ac for trees 9 inches d.b.h. or greater where there are at least 109 trees per acre that are 9 inches d.b.h. or less. This prescription may be applied in all stands excluding lodgepole, white pine, grand fir and sub alpine fir.

2) **Moderate density (Moderate)** – cut and remove all trees up to 7 inches d.b.h., plus some larger diameter trees with a target residual stand having 100 ft^2/ac BA in the largest and healthiest trees; apply this prescription

only to stands having a BA greater than 100 ft^2/ac for trees 7 inches d.b.h. or greater. Grand fir and sub alpine fir are removed first, and then the smallest Douglas fir, ponderosa pine and western larch are cut equally until the desired BA is achieved. This prescription may be applied in all stands excluding lodgepole and white pine.

3) **Comprehensive restoration (Comprehensive)** – cut and remove all trees up to 7 inches d.b.h., plus some larger diameter trees with a target residual stand having 50 ft^2/ac in fire resistant tree species such as ponderosa pine, western larch, and large Douglas fir. Remaining tree sizes, numbers, and their locations will restore the stand to a sustainable structure given current conditions. Apply this prescription only to stands having a BA greater than 50 ft^2/ac for trees 7 inches d.b.h. or greater. This prescription was designed for application in ponderosa pine habitat types only.

Timber Volume Estimation

Forest Inventory and Analysis (FIA, http://www.fia.fs.fed.us/) data were used to estimate the volume of merchantable logs (7+ inches d.b.h. to a 4.5 inch top) and sub-merchantable biomass (whole trees less than 7 inches d.b.h. and tops and limbs of harvested trees 7+ inches d.b.h.) that would be removed by the three mechanical fuel reduction prescriptions. A whole tree harvest system was assumed. To obtain an adequate amount of stand data, FIA plots were selected from six western Montana counties having forest conditions similar to those found in Ravalli County, yielding a total of 912 FIA plots.

These data were imported into the Northern Idaho/Inland Empire variant of the Forest Vegetation Simulator (FVS, http://www.fs.fed.us/fmsc/fvs/) to predict merchantable timber volumes and biomass harvested from applying each of the three fuel treatment prescriptions described earlier. We assumed that no cut stems, tops, or branchwood were left in the stand, in other words everything cut was removed.

To capture the dynamic aspect of timber stand composition over time, as well as to allow stands to move between vegetation states, the FIA plot growth was simulated using FVS for up to five decades from 1997, the most recent inventory year, to 2007,…, 2047. Each plot was grown from its inventory condition to each of these decadal time periods and then the fuel treatment prescriptions were applied. Based on the forest conditions for applying each of the three treatments, the Comprehensive prescription set consisted of 2,703 plots, the Moderate prescription set had 1,346 plots and the TB9 prescription set had 2,267 plots. Many plots qualified for more than one prescription.

Weights for all merchantable logs that would be removed from the FIA plots by the prescriptions were computed through a combination of the FVS Database Extension, tree component ratio equations from Jenkins and others (2003), and dry cubic foot weights obtained from Reinhardt and Crookston (2004). Quadratic mean diameter (QMD) and trees per acre cut were tallied for both the merchantable and non-merchantable categories. The Fire and Fuels Extension was utilized to estimate the weight of the total biomass removed. Subtracting the removed merchantable log weight from the weight of the total biomass removed yielded weight of the sub- or non-merchantable biomass. We assumed that all cut stems and branchwood were removed from the stand (FVS YARDLOSS keyword). Statistics are displayed in tables 1 through 3.

Table 1—Summary statistics of quadratic mean diameter (QMD), cubic feet, trees per acre cut, biomass, and harvest costs for trees removed using the Comprehensive prescription (n=2,703).

Statistics	QMD >7" DBH	QMD <=7" DBH	Cubic Ft >7" DBH	Cubic Ft <=7" DBH	Trees per Acre Cut >7" DBH	Trees per Acre Cut <=7" DBH	Total Removed (dry tons)	Biomass (dry tons)	Harvest Cost per Acre: With Biomass Chipping	Harvest Cost per Acre: Without Biomass Chipping
Mean	11.93	3.53	1,740.77	269.07	97.69	215.31	39.22	13.09	$1,595	$1,458
Std. Error of Mean	0.06	0.04	25.06	6.47	1.20	6.59	0.45	0.15	$19	$17
Std. Deviation	3.13	1.98	1,302.63	336.38	62.57	342.62	23.63	7.97	$980	$897
Median	11.27	3.84	1,471.76	148.41	87.64	95.81	36.00	11.81	$1,468	$1,335

Table 2—Summary statistics of quadratic mean diameter (QMD), cubic feet, trees per acre cut, biomass, and harvest costs for trees removed using the Moderate prescription (n=1,346).

Statistics	QMD >7" DBH	QMD <=7" DBH	Cubic Ft >7" DBH	Cubic Ft <=7" DBH	Trees per Acre Cut >7" DBH	Trees per Acre Cut <=7" DBH	Total Removed (dry tons)	Biomass (dry tons)	Harvest Cost per Acre: With Biomass Chipping	Harvest Cost per Acre: Without Biomass Chipping
Mean	10.29	3.71	1,126.87	250.82	80.21	201.11	27.09	10.37	$1,223	$1,117
Std. Error of Mean	0.07	0.05	28.17	7.91	1.51	8.79	0.51	0.18	$22	$20
Std. Deviation	2.40	1.89	1,033.35	290.18	55.42	322.38	18.68	6.78	$804	$736
Median	9.83	4.01	834.83	155.24	70.38	94.53	23.00	8.95	$1,067	$968

Table 3—Summary statistics of quadratic mean diameter (QMD), cubic feet, trees per acre cut, biomass, and harvest costs for trees removed using the TB9 prescription (n=2,267).

Statistics	QMD >7" DBH	QMD <=7" DBH	Cubic Ft >7" DBH	Cubic Ft <=7" DBH	Trees per Acre Cut >7" DBH	Trees per Acre Cut <=7" DBH	Total Removed (dry tons)	Biomass (dry tons)	Harvest Cost per Acre: With Biomass Chipping	Harvest Cost per Acre: Without Biomass Chipping
Mean	6.93	3.93	261.98	304.70	42.21	250.10	12.30	8.26	$763	$693
Std. Error of Mean	0.06	0.04	5.38	7.02	0.82	7.55	0.22	0.16	$16	$14
Std. Deviation	2.77	1.74	255.92	334.10	39.15	359.57	10.36	7.61	$738	$673
Median	7.93	4.12	187.99	192.20	32.13	131.55	10.00	6.00	$562	$517

Modeling Treatment Costs

Treatment costs (excluding administrative and planning) were modeled for each application of the three treatments applied to the FIA plots summarized in tables 1 to 3 using the Fuel Reduction Cost Simulator (FRCS, Fight and others 2006). Required FRCS input variables include trees per acre removed, QMD, average tree volume, green wood weight, and residue weight to bole weight fractions. These were calculated from the cut tree lists (tables 1 to 3), regression equations from Jenkins and others (2003) and dry wood weights from Reinhardt and Crookston (2004) adjusted to 50 percent wood fiber moisture content. We used the average slope of 22 percent for lands identified through GIS analysis. We specified a whole tree system with an average skidding distance of 800 feet. The model was calibrated to reflect western Montana wage rates – $24.60/hour for fallers and/or buckers and $16.13/hour for all others (2002 dollars, ACINET 2003). The model's default labor benefit rate of 35 percent was retained, and move-in costs were not included. Tables 1 to 3 display summary statistics from the harvest cost modeling.

Haul Cost Estimation

Material delivery costs from the logging unit to an end use facility can often determine the financial success of mechanical treatment operations. Western Montana is home to several locations that utilize biomass as thermal-energy fuel, and therefore, haul distances are not as great as many other locations. For our analysis we specified two end use locations as destinations for the biomass and one end use facility for merchantable logs that resulted from implementing the three fuel reduction prescriptions. These are respectively the towns of Darby in the southern portion of Ravalli County, Frenchtown in western Missoula County and Milltown in southern Missoula County (fig. 1).

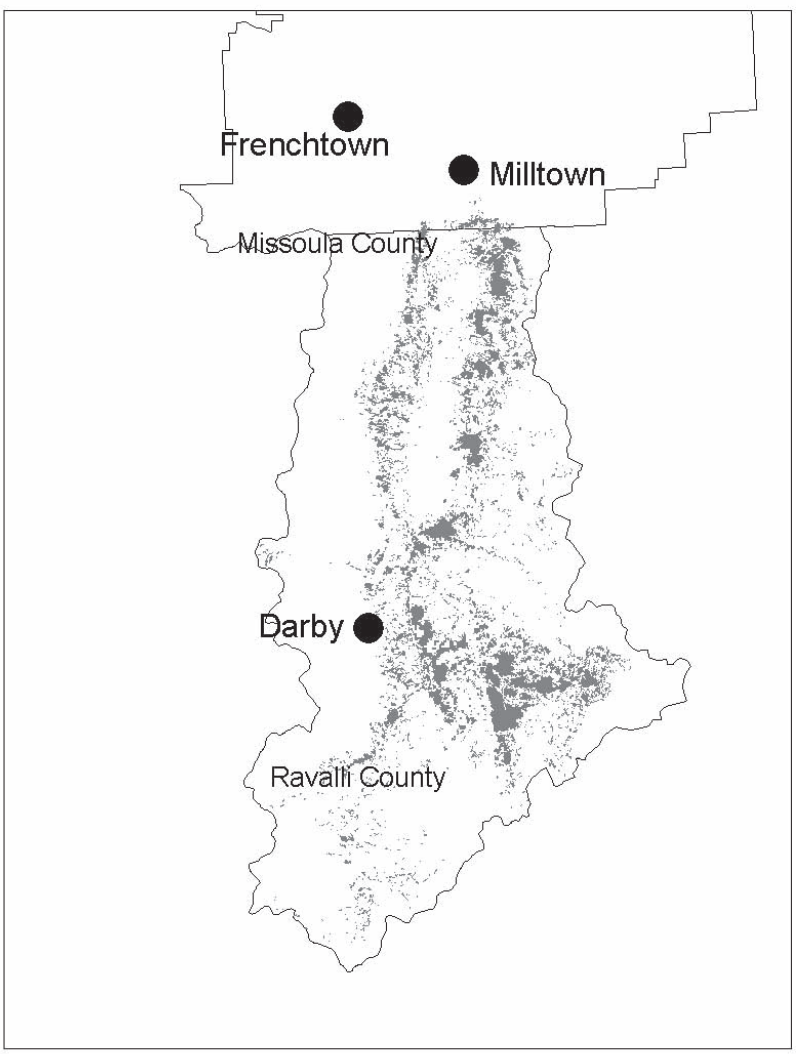

Figure 1—Location of delivery points. Darby and Frenchtown for biomass. Milltown for timber products. Gray shaded area is the study area polygons.

Haul costs were estimated on a per mile basis for each of two types of roads, paved and non-paved, using the Forest Residue Trucking Model (FoRTS; http://www.srs.fs.usda.gov/forestops/) and a GIS road coverage for the study area (Loeffler and others 2006). We further verified our results from FoRTS with the Log Truck Haul Cost Appraisal model (http://www.fs.fed.us/r6/nr/fp/FPWebPage/FP70104A/Programs.htm). Chip truck haul costs were based upon hourly roll-off container truck operating costs and average miles per hour speed, and log truck haul costs were based upon the hourly costs of operating a tractor trailer. We calibrated the haul cost model to reflect local wages and conditions using an average driver wage of $16/hour with 35 percent benefit rate. We assumed the chip truck would haul 16 green tons of chips and the log truck 28 tons, diesel fuel costs $2.50/gallon and oil costs $9/gallon.

We estimated haul costs for log trucks delivering merchantable logs to Milltown (where a mill exists that purchases logs) and roll-off container trucks hauling biomass to both Frenchtown and Darby. Distances in both paved and non-paved miles (total miles is the sum of paved and non-paved) were tallied from the polygons identified in the GIS portion of this analysis to Darby, Frenchtown, and Milltown. Average speeds were estimated at 15 miles per hour on non-paved roads and 45 miles per hour on paved roads. Using these estimates, costs per mile for each road surface type were estimated using the FoRTS model as the quotient of operating costs per driving hour and average miles per hour speed (table 4). Differences in the costs per mile are attributable to changes in variable truck operating costs when combinations of road types change. These average costs per mile were then multiplied by the actual paved and unpaved distances for each polygon to compute unique haul costs for each polygon.

Selection of Analysis Area

GIS data were used to identify the stands in the frequent fire regime class where mechanical treatment is appropriate and feasible. The current vegetation was represented by the vegetation states assigned to the stand polygons by Chew and others (2004). Based on fuel management objectives, only those vegetation states having the dominant tree species displayed in table 5 were considered for treatment. Additional characteristics of vegetation states included size class (QMD of SS = <5", Pole = 5" to 8.9", Medium = 9" to 14.9", Large = 15" to 20.9", and Very large = 21"+) and density (crown canopy cover of 1 = 0 to 15%, 2 = 15 to 39%, 3 = 40 to 69%, 4 = 70 to 100%). The FIA plots were categorized into these pre-treatment vegetation states. Since FIA data did not exist for certain vegetation states (21 percent by area), missing data was interpolated through a method of substituting

Table 4—Round trip distances and haul cost to the three end use locations.

End Use Locations - Montana towns	Average Round Trip Miles		Cost per Mile	
	Paved Roads	Non-paved Roads	Paved Roads	Non-paved Roads
Darby (chip truck)	38	13	$1.26	$3.78
Frenchtown (chip truck)	134	16	$1.37	$4.10
Milltown (log truck)	124	16	$1.36	$4.08

Table 5—Tree species combinations selected for analysis.

Dominant species	Descriptions
DF	Douglas-fir (*Pseudotsuga menziesii*)
DF-GF	Douglas-fir - Grand fir (*Abies grandis*)
DF-LP	Douglas-fir - Lodgepole pine (*Pinus contorta*)
DF-LP-AF	Douglas-fir - Lodgepole pine - Subalpine fir (*Abies lasiocarpa*)
L-DF-LP	Western larch (*Laryx occidentalis*) - Douglas-fir - Lodgepole pine
L-DF-PP	Western larch - Douglas-fir - Ponderosa pine (*Pinus ponderosa*)
PP	Ponderosa pine
PP-DF	Ponderosa pine - Douglas-fir

based on proportional data from other vegetation states. From the GIS data we restricted analysis to non-wilderness areas, with slopes less than or equal to 35 percent (based on the requirements of the whole tree ground-based harvest system), only lands categorized as FRCC 2 or 3 (USFS 2003b) and polygons that fell within a 1500 foot buffer of existing roads. The resulting polygons are included in figure 1.

MAGIS Modeling Parameters

MAGIS (Multi-resource Analysis and Geographic Information System) is an optimization model designed to solve complex spatial and temporal scheduling problems in natural resource management (Zuuring and others 1995). MAGIS is based on a mixed-integer mathematical programming formulation that includes vegetation management options for treatment unit polygons and an optional network component for analyzing road access and associated costs and resource impacts (Weintraub and others 1994). Decision variables for each treatment unit polygon include "no action" and treatment options comprised of alternative management regimes that vary by the treatment(s) they prescribe over time, and the period when the management regime is implemented.

The objective of this study was to analyze the quantities of biomass that could be made available by treating hazardous fuels accessible from existing roads. Haul distances and costs were incorporated into the vegetation management alternatives along with costs of burning biomass on site. Separate decision variables were created for each combination of vegetation management treatment option (TB9, Moderate, and Comprehensive) and the three options for biomass disposal from the treatments: Burning (pile burning at logging site), biomass hauled to Darby, and biomass hauled to Frenchtown. This resulted in up to nine possible treatment choices for the optimization solver to choose from for each treatment unit polygon.

Vegetation Succession—Successional pathways were used to determine changes in vegetation states in 5 decadal time steps (50 year planning horizon) if no hazardous fuel treatment is undertaken. These predicted states describe the vegetation that would exist when the future treatment options would occur. The most important successional pathways in terms of acres are listed in table 6.

Table 6—Pathways for the major vegetation states in the study area.

Habitat group[a]	Initial dominant species, size class, density	Acres (1000)	Successional changes: resulting dominant species, size class, density
B2	PP, SS, 2	76	4th decade goes to PP, Pole, 2 5th decade goes to PP-DF, Pole, 2
A2	PP, SS, 2	16	3rd decade goes to PP, Pole, 2 5th decade goes to PP, Medium, 2
B2	L-DF-PP, Large, 3	13	no changes
B2	L-DF-PP, Medium, 3	12	2nd decade goes to L-DF-PP, Medium, 4 5th decade goes to L-DF-PP, Large, 4
B2	DF, Large, 3	7	no changes
B2	DF, Medium, 3	5	2nd decade goes to DF, Large, 3

[a] Habitat group descriptions: A2 is warm and dry, and B2 is moderately warm and dry.

Effects Functions—Functions that were used as constraints or objectives by period within the model consisted of the following:

1) Total acreage functions: total acres: treated, treated with TB9, treated with Comprehensive, treated with Moderate, with biomass removal, with pile burning, of FRCC treated (class 2 and 3, tabulated separately), and of WUI treated
2) Cost functions: total costs, cost of biomass removal (stump-to-truck and chipping), site costs (merchantable (stump to truck) and any biomass removal or preparation for pile burning), haul costs of biomass (to Darby or Frenchtown, tabulated separately), haul costs of merchantable (to Milltown), and costs of pile burning
3) Revenue functions: biomass revenue, merchantable revenue, and total revenue
4) Net value functions: total net value (total revenues minus total costs), biomass net value (biomass revenue minus biomass removal and haul costs)
5) Volume/weight functions: merchantable volume and biomass weight

These functions incorporate the volume and cost computations described earlier. The value of delivered merchantable material was set at $2 per cubic foot, and the value of delivered biomass was set at $13 per green ton. Both values were based on current local markets. The cost of pile burning was estimated at $100 per acre.

Results

MAGIS can be used to develop many types of spatial and temporal analyses. We present five analyses that capture the economic aspects of utilizing biomass produced by mechanical hazardous fuel treatments. For each, we describe the question, the MAGIS set up and runs made to address the question, then present the results.

Maximum Net Value by Treatment Prescription

This section investigates the extent to which each of the three mechanical fuel treatment prescriptions result in a positive net return, and the number of treatment acres expected to result in a positive net return. Three scenarios were run that constrained treatment prescription to biomass utilization first to only the Comprehensive prescription, next to only the Moderate prescription, and last to only the TB9 prescription. Each scenario optimized on the objective function of maximum net value in period one. The results showed that acres that could be treated with a positive return were 20,984, 56,421, and 60,689 for TB9, Moderate, and Comprehensive, respectively, from 160,954 treatable acres in the study area. The costs, revenues, and net values per acre for these prescriptions are displayed in figure 2. The vast majority of the total revenue predicted for these treatments comes from the commercial component that would be removed. The Comprehensive prescription had an understandably higher net value than the TB9, with the Moderate prescription falling in between, as was expected from the level of commercial products each prescription produces. The net values per acre treated for positive valued units for TB9, Moderate, and Comprehensive were $83, $1,632, and $2,939, respectively, which support the basic findings Fiedler and others (1999) with regard to the economic value of the Comprehensive prescription.

A Spatial View of Economic Importance of Biomass Mill Location

Haul costs are known to be an important economic component in the feasibility of off-site biomass utilization. As such, the location of biomass markets affects the economics of biomass utilization. In this section we compare the economics of biomass utilization with on-site burning for three biomass market scenarios: 1) markets at both Darby and Frenchtown, 2) market only at Darby, and 3) market only at Frenchtown. In each scenario we assume the markets can utilize all the biomass these scenarios would deliver. All three scenarios maximized net value in period one as the objective function and

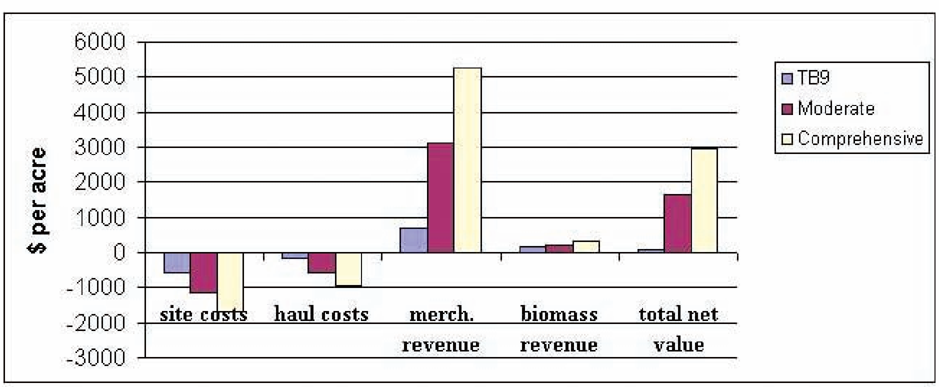

Figure 2—Costs, revenues and resulting net value for the three mechanical fuel treatment prescriptions applied where they result in positive returns. Site costs include merchantable (stump-to-truck) and any biomass removal (stump-to-truck and chipping) or preparation for pile burning. Haul costs include hauling merchantable material and biomass for biomass scenario. Merch revenue is the revenue for merchantable material.

constrained acres treated to include all that were treatable. The first scenario (markets at both Darby and Frenchtown) had no other constraints. The second scenario constrained biomass delivery to Darby only. The third scenario constrained delivery to Frenchtown only.

Results mapped in figure 3, panels a to c, show the most economical disposal of biomass for each polygon. When delivery was allowed to both Darby and Frenchtown, it was most economical to deliver 82 percent (by area treated) of the biomass to centrally located Darby, while the northern 16 percent of biomass went to Frenchtown, north of the study area, and only 2 percent was burned on the peripheral units (fig. 3, panel a). When Darby was the only location, biomass delivery (97 percent) was more economic than burning (3 percent) (fig. 3, panel b). Finally, when Frenchtown was the only location, biomass delivery fell to 57 percent and burning increased to 43 percent (fig. 3, panel c). In this scenario, burning was more cost effective in the southern area away from the northern mill site and the paved delivery routes that run down the center of the study area. This result clearly shows the importance of biomass markets nearer to the forest resources, whereby Darby, with an average haul distance of 25 miles one-way, showed biomass utilization to be profitable in 97 percent of the area, whereas Frenchtown, with an average haul distance of 75 miles one-way, showed biomass utilization to be profitable in only 57 percent of the area.

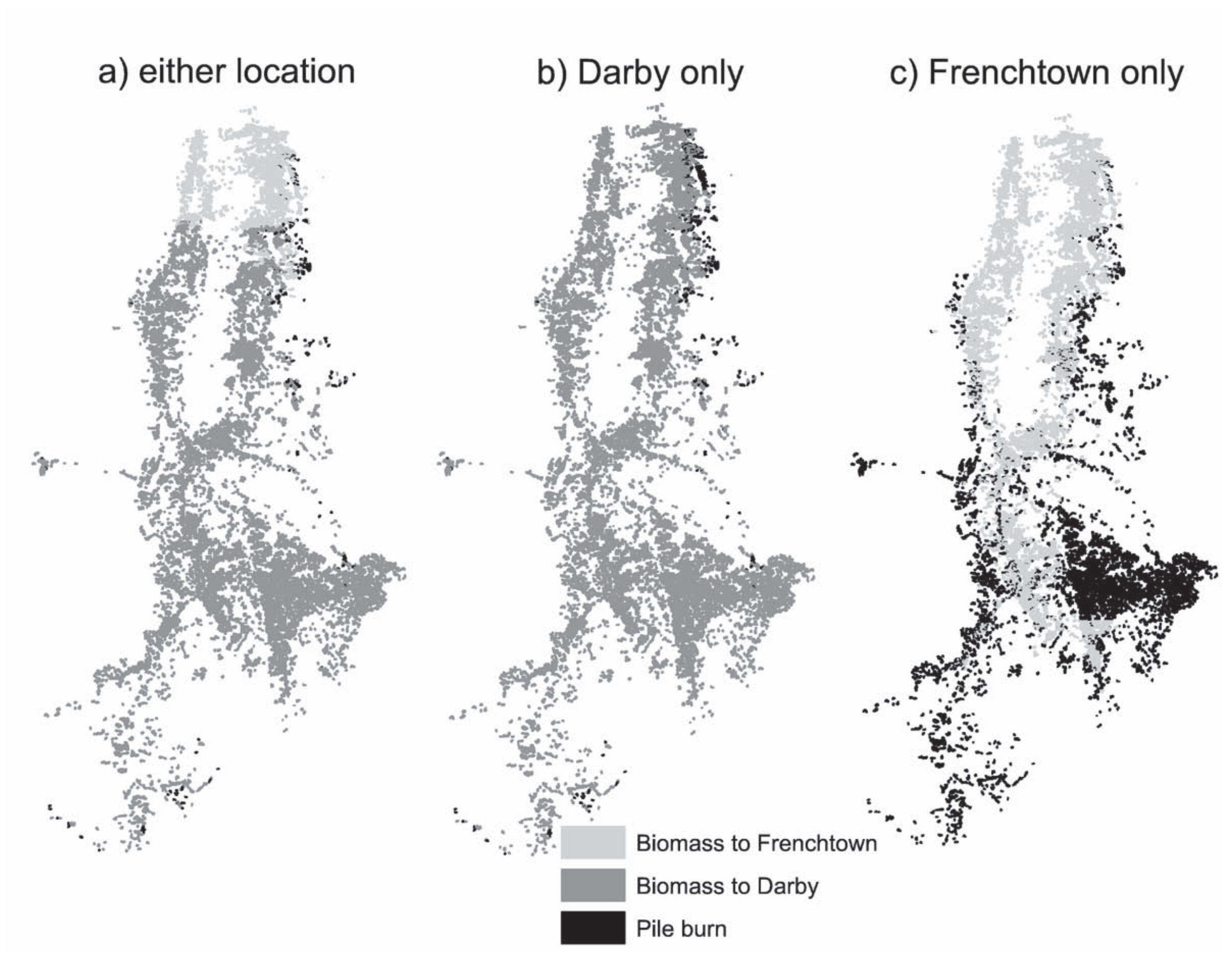

Figure 3—Spatial view of use of small diameter materials to maximize net value for all treatable acres for three biomass market scenarios: a) markets at both Darby and Frenchtown; b) market at Darby only; and c) market at Frenchtown only. See figure 1 for mill locations.

Biomass Utilization versus Burning for Selected Zones

We also compared the economics of utilizing biomass created by mechanical fuel treatments with pile burning within specific zones, first all acres in FRCC class 3, and next in WUI acres. For this comparison, net value was maximized for scenarios that treated all 71,984 acres of FRCC class 3 and all 119,126 acres of WUI with either solely biomass utilization or solely pile burning in period one. Utilizing biomass while treating all FRCC class 3 acres resulted in a positive average net value for applying mechanical fuel reduction treatments, whereas pile burning resulted in a negative average net value. As can be seen in figure 4, the additional revenue came primarily from biomass, which offset increased haul costs enough to show the positive return. The biomass revenue is understandably high in FRCC 3 areas as this indicates a fire regime condition class that has grown with thicker forests which would provide more biomass in these mechanical fuel treatments. Treating WUI acres showed positive net values for biomass utilization and burning, with modest increases from biomass revenue offsetting haul costs (fig. 5). The WUI zone generated higher merchantable revenue than the FRCC 3 zone because of a higher percentage of area in size classes over 9" d.b.h. (27 percent for WUI versus 11 percent for FRCC 3).

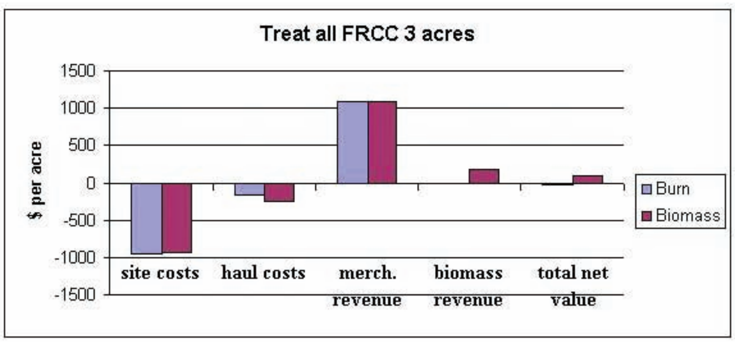

Figure 4—Costs, revenues and resulting net value for treatment of all FRCC 3 acres exclusively using biomass utilization or burning. Site costs include merchantable (stump to truck) and any biomass removal (stump to truck and chipping) or preparation for pile burning. Haul costs include hauling merchantable material and biomass for biomass scenario. Merch. revenue is the revenue from merchantable material.

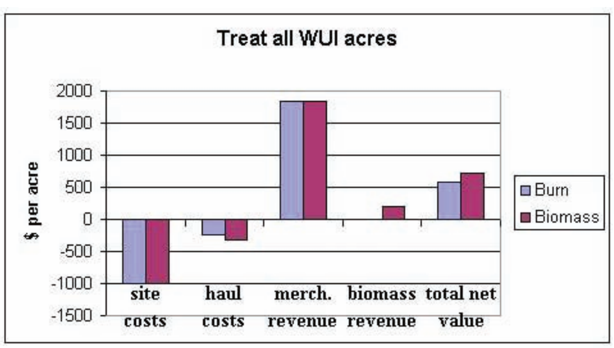

Figure 5—Costs, revenues and resulting net value for treatment of all WUI acres exclusively using biomass utilization or burning. Categories as defined in figure 4.

Comparing Biomass Utilization with Pile Burning for TB9 on Lands Classified as FRCC 3

Brown (2000) cautioned land management agencies regarding public perception of the removal of large merchantable trees during fuel treatment projects. Some public factions prefer fuel treatments that remove only understory ladder fuels and no larger trees. Results presented earlier show that this approach represented by TB9 in this study is more economically challenging than the other two prescriptions which do remove some larger trees having a commercial value. Here we investigate what effects biomass utilization has on the ability to accomplish TB9 treatments for specific budget levels. We focus attention on the FRCC class 3 acres, those presumably most in need of mechanical fuel treatments. Although treating all FRCC class 3 stands resulted in a positive net value with biomass utilization when all treatment prescriptions were available (fig. 4), limiting the options to only TB9 yields a negative net value, requiring a net cost outlay to perform treatments. This analysis was accomplished by running scenarios with five different budget levels for treatments in period one. Budget levels were set at $0, 10, 20, 30, and 35 million dollars, by constraining net value to be greater than the negative of these values. One scenario with only burning and one with only biomass utilization were run for each budget level. The objective function in each scenario was to maximize total acres treated.

The resulting graphs, comparing with and without biomass utilization, suggest that biomass utilization can make a large difference in making limited budgets go further in treating the landscape (fig. 6). For example, at the $20 million level, utilizing biomass increases acres treated from 60 percent with only burning to 76 percent. Similarly, treating 60,000 acres would cost approximately $22 million with biomass and $29 million without biomass.

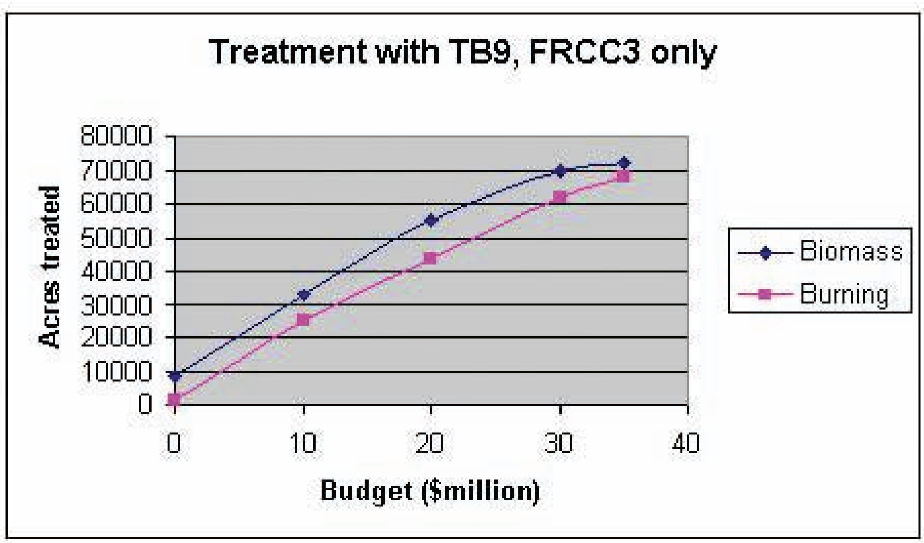

Figure 6—Period one treatment with TB9 in the FRCC3 zone only, constrained by different budget levels.

Even Flow of Biomass Utilization Across Five Decades

Is biomass produced by mechanical fuel treatments sustainable over time? This is an important question for potential investors in new biomass processing facilities. To address this question multiple scenarios were run to identify the maximum sustainable biomass quantity per decade from mechanical fuel treatments over five decades. This was accomplished by constraining the periods 2 through 5 biomass volumes to identical minimum levels and then using the biomass volume in period 1 as the objective function in successive solutions until the resulting period one biomass volume equaled the constrained level for the other periods. This occurred at 758,800 tons of biomass volume per decade.

Next we looked at the amount of biomass that would be produced at different levels of acres treated per decade. These scenarios set constraints at intervals of 5,000 acres treated per decade and used an even-flow of net value as the objective function. The outcome provides economically efficient biomass volumes per decade at different treatment levels (fig. 7). After 15,000 acres per decade, the rate of increase in additional biomass volume with additional acres treated drops as a point of maximum efficiency is reached.

Discussion

Our findings demonstrate that utilizing small diameter wood can enhance the economics of performing fuel treatments to reduce the risk of wildfire and restore forests to natural conditions. By applying a common mechanical fuel treatment prescription, in many instances it is more efficient to extract and utilize the biomass than it is to pile and burn it on site. The breakeven

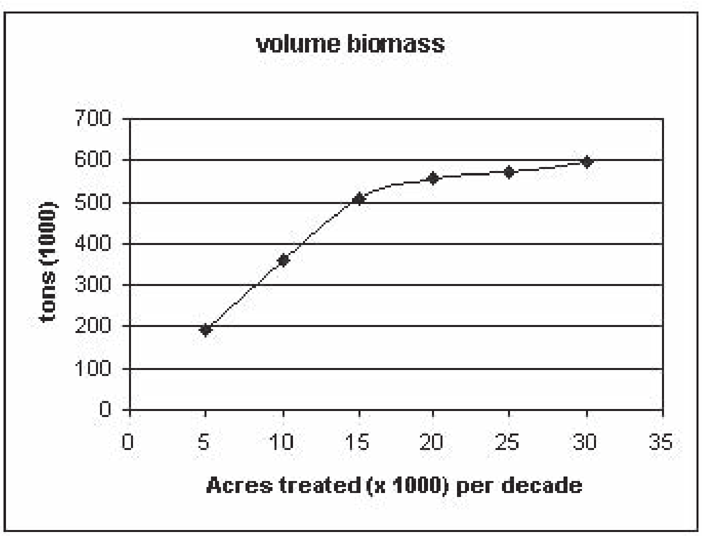

Figure 7—The volume of biomass per decade obtainable with treatments that maximized even-flow net value at different levels.

point between biomass utilization and pile and burning is dependent on haul distances and costs to biomass markets as shown in the maps presented in figure 3. The advantage of biomass utilization is also present in the thin from below prescription, TB9, which removes very little commercial product. These analyses show that the acres that can be treated by TB9 within a fixed budget can be increased by utilizing the biomass created by the treatment rather than pile and burning it on site.

For this paper we analyzed the economics of biomass utilization when conducting fuel treatments focusing on maximizing net value for the majority of the spatial and temporal modeling. However, the principles and the modeling techniques developed here could easily be adopted by managers and planners with different objectives. For example, considerable effort has been invested into determining where best to place fuel treatments to reduce the risk of wildfire (Weise and others 1999, Agee and others 2000, Hof and Omi 2003, Jones and others 2003). Treatment locations can be based on predictions of fire behavior models that do not consider economics (Finney 2001). However, the modeling system presented here is flexible and indices such as crown fire reduction or fire spread rates (Finney 2003) could also be used as the driver to guide treatment placement. With this approach, analysis can be conducted that considers both fire behavior (through use of the crown fire reduction or fire spread indexes) and economics in locating places to apply treatments.

For businesses to establish small diameter wood processing facilities, a guaranteed, long term supply is necessary (Stewart and others 2004; Keegan and others 2005). The analysis presented in this paper indicates that with the current fuels conditions and expected growth of forest fuels in the future as quantified in the successional pathways, significant sustainable volumes of biomass could be made available from applying mechanical fuel treatments to acres in need of fuel reduction treatments over the next five decades. The aspect of this question we have not been able to analyze is whether these mechanical treatments will actually occur on the ground, which on public land is dependent largely on local as well as national political and legal processes.

There are understandable environmental concerns when proposing the removal of vast quantities of woody material from a national forest. Our analysis found the Comprehensive prescription to be the most economically efficient method of treating the landscape and utilizing biomass in the process. Although this was designed as a prescription for ecological restoration (Fiedler and others 1999), the present political climate which influences management decisions indicates extraction of this much material would likely be controversial, whether or not environmentally sound. The TB9 prescription, on the other hand, has the potential to address the fire danger problem with less controversy, though at higher net costs, as shown here, and perhaps less effectively (Fiedler and others 2003). Furthermore, establishing markets for biomass utilization to face the immediate problem of overstocked forests has the potential to create a future demand for forest products that can not be met in an ecologically sound way once the ecosystems are truly restored. The even-flow analysis indicated this is not an immediate concern in the study area, but ecological restoration may occur much sooner in other locations. Thus, the question of sustainability is important for environmental as well as economic reasons, and would be an important direction for further research to expand on what we have begun here.

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